2 Biological Resources

A cormorant dries its wings. | *Mike Yip*

1. Overview

Puget Sound's biological resources include all living organisms that inhabit the marine waters and shorelines. These resources are plankton, invertebrates, fish, birds, mammals, and aquatic vegetation, including species that are either residential or migratory.

Significant changes in the biological communities of Puget Sound have occurred in the past 30 years, including declines in forage fish, salmonids, bottomfish, marine birds, and orcas. These changes have not gone unnoticed, resulting in restricted and closed fisheries, petitions to list species under state programs and the federal Endangered Species Act (ESA), and development of recovery and management plans for several species. Coordinated efforts by PSAMP and other monitoring and research programs have been underway to evaluate the declines, identify the stressors affecting the populations, and develop actions and solutions to stem the declines and begin rebuilding populations of species at risk.

Many stressors are affecting or have affected biota in Puget Sound in ways that we are only beginning to understand. These include climate change, toxic contamination, eutrophication (low oxygen due to excess nutrients), and nearshore habitat alteration.

This chapter characterizes what is known about the many biological components of the Puget Sound ecosystem and, when possible, provides information about the status and trends of each resource. Where appropriate, the factors that limit or enhance the biological component will be identified, discussed, and linked with other sections of the *Puget Sound Update*.

Our knowledge of the Puget Sound ecosystem is still developing. While this section presents species-specific information on status and trends, sophisticated models of trophic, demographic, and population stressors that link the different components of the ecosystem are only beginning to be developed. In time, scientists will be able to predict the impact of stressors, understand natural variation, and link peaks and valleys of one species with those of others. The information presented in this section, however, does represent the most comprehensive look ever taken at Puget Sound biological resources.

Key findings from this chapter include:

- Nearly 60 percent of groundfish stocks in Puget Sound are in good condition. Those in decline include middle-trophic level predators such as **rockfishes**, **spiny dogfish**, **Pacific cod,** and **hake**.
- Spawning potential for **copper and quillback rockfish** dropped by nearly 75 percent between 1970 and 1999, and more recent information confirms a continued decline. Although the overall number of groundfish has not changed significantly in the last few decades, many popular harvest species have sharply declined while others have increased.
- The total **Pacific herring** population from Puget Sound's 19 stocks has declined since 2002, with the most significant change occurring in north Puget Sound. Here, stocks dropped from a peak of approximately 12,000 tons of spawning biomass in to a low of 4,000 tons in 2004. The Cherry Point stock of North Puget Sound have had particularly large declines in recent years, dropping from 3,000 tons in 1996 to approximately 800 tons in 2000. In 2006, total herring biomass estimate is 12,000 tons.
- Southern resident **orcas** were listed on the federal endangered species list in 2005. The population currently consists of86 whales, down from a peak of 98 in 1975.
- **Surf scoters, white-winged scoters,** and **black scoters** have collectively declined by approximately 57 percent between 1978 and 1999. This decline has continued from 1999 through 2005 in nearly all of the subregions of Puget Sound. The decrease in scoters represents the largest decline in biomass of marine birds over the last 25 years in Puget Sound.
- **Loons** and **grebes** that over-winter in Puget Sound have declined by nearly 75 percent over the past 10 years. It is unknown whether this reflects declines in the overall populations or whether birds are over-wintering outside of Puget Sound.
- Native **eelgrass** has declined in Hood Canal for four consecutive years since 2001. The San Juan Archipelago has experienced declines in small embayments. In eleven embayments approximately 83 acres of eelgrass were lost between 1995 and 2004.
- **Sea lions** have become more abundant in Washington waters. The California sea lion populations have increased by about 5 percent annually, with a current population of 4,000 - 5,000 animals. Stellar sea lions are also increasing in population, by about 10 percent annually. Surveys conducted in 2005 of stellar sea lions during peak abundances in fall and winter recorded 1,000 - 1,500 sea lions along Washington's outer coast. This species also regularly inhabits North Puget Sound.

- **Harbor seals** have been steadily increasing in population since the early 1970s, with current populations consisting of 16,000 seals along the outer Washington Coast and 14,000 in the inland waters of Puget Sound.
- The **pinto abalone**, a once fairly abundant native species in Hood Canal, north Puget Sound and the San Juan Islands, appears to be critically depressed and in such low abundance that this species may be unable to naturally reproduce. In the San Juan Archipelago, between 1992 and 2005, abalone have declined from 351 animals per site to 103 animals per site at 10 long-term monitoring stations.
- Restoration of the **Olympia oyster**, a native shellfish species, has been successful in expanding the oyster's historic range in Puget Sound.
- Results from monitoring **marine reserves** in Puget Sound have shown that, within a decade, lingcod have become abundant and, as top predators, are keystone species that help characterize the trophic and ecological structures of rocky habitats.

2. Species of Concern

Species of concern are native species that warrant special attention to ensure their conservation. Within the Puget Sound region, the state of Washington and the federal government assess which species require special initiatives to ensure protection and survival of their populations. A recent study (Gaydos 2004) identified 47 marine species of concern in the Puget Sound—three invertebrates, 23 fishes, one reptile, 11 birds, and nine mammals (Table 2-1). (A full list of federal and state listed species is contained in Appendix A). In status reviews conducted for the 14 species listed as threatened or endangered by Washington state or the federal government, contaminants, habitat loss, and over-harvest were the most frequent causes cited for species declines.

	Washington State	U.S.A.	TOTAL
Invertebrates	3	2	**3**
Fishes	23	6	**27**
Reptiles	1	1	**1**
Birds	11	7	**23**
Mammals	9	4	**9**
Total	**47**	**20**	**63**

Table 2-1. Total number of species of concern in Washington, listed by state and federal government.

3. Plankton

Plankton are single-celled and multicellular organisms that float in the water and are the basis of the marine food web. While some are mobile, most plankton species are dispersed by the action of tides and currents. There are two major types of plankton: phytoplankton and zooplankton.

Phytoplankton are microscopic plants that contain chlorophyll-*a*, the main pigment involved in photosynthesis, and draw energy from sunlight and nutrients in the water column. They are comprised mainly of diatoms and dinoflagellates, with diatoms accounting for most of the phytoplankton biomass in Puget Sound.

Glowing plankton

Named for its ability to bioluminesce, or glow, at night, *Noctiluca scintillans* is a large dinoflagellate species. *Noctiluca sp*. is not photosynthetic, because it has no pigments of its own, but obtains the pigment from the phytoplankton it feeds on. This organisms belongs to the group of red tide-forming organisms, but unlike some red tides, it does not produce toxins and is not harmful to humans or marine organisms. However, when large blooms start to decay, they can deplete oxygen in the water column to levels where fish and other organisms become stressed or die. In daylight, large accumulations of *Noctiluca* appear to be orange-red to rust brown, resembling tomato soup. For several weeks during late spring or early summer, this organism is often found in Central Puget Sound.

Under certain conditions, phytoplankton can form large accumulations, referred to as blooms. Daily plankton productivity rates in Puget Sound are among the highest of West Coast estuaries (Emmett et al. 2000). Diatoms dominate phytoplankton populations in fall and winter and during spring blooms, while dinoflagellates become more abundant in spring and summer.

Zooplankton are the animal components of the plankton and include invertebrates such as crustaceans and jellies, as well as fish larvae. Zooplankton are not photosynthetic and generally consume other plankton species. Phytoplankton and zooplankton are critical components of Puget Sound's food web, but their distributions, abundances, and life histories are not well understood.

a. Phytoplankton

Phytoplankton levels in Puget Sound vary, depending on the time of year, and are driven mainly by light and nutrient availability. When the ideal combination of conditions exists, plankton blooms can occur. Such blooms can last from days to weeks. The geographic distribution and abundance of phytoplankton is linked to nutrient upwelling, river runoff, stratification, mixing of surface waters, and wind—all important factors in providing nutrients for plankton growth. These conditions also influence the duration (or residence time) of plankton blooms within a basin. For example, at the Tacoma Narrows, the upwelling of nutrients to surface waters caused by tidal mixing helps support the high productivity of the Central Puget Sound Basin. Remixing of the upper water layer into deeper waters in Admiralty Inlet causes an increase in chlorophyll and a decrease in nutrients at depth in this area (Boss et al. 1998).

Factors such as turbidity, surface water mixing, and zooplankton abundance also influence the occurrence of phytoplankton blooms. The annual productivity of Elliott Bay, for example, has been estimated to be about two-thirds less than the rest of the Central Basin (Strickland 1983) because of turbidity and short residence times when there are high freshwater flows from the Duwamish River. When the freshwater flow from the Duwamish River is low, large blooms can occur because residence time of water in Elliott Bay is longer, allowing an opportunity for phytoplankton to accumulate (Strickland 1983). This pattern is typical of other Puget Sound embayments that have significant seasonal freshwater inputs.

Status and Trends

King County and Ecology conduct monthly water column measurements throughout Puget Sound to estimate chlorophyll-*a* concentrations. Although phytoplankton growth and abundance varies in geographic location and timing from year to year, most large phytoplankton blooms[1] typically occur from April through July, although large blooms can occur in late winter and late summer/early fall[2] (Figure 2-1). For example, in 2005, an April bloom at the King County monitoring stations appears to have been due to early stratification of the water column caused by warm air temperatures and lack of cloud cover. In contrast, the absence of a fall bloom in September 2004 may be attributed to lower-than-normal water and air temperatures compared to the past 30-year average.

[1]Bloom is defined as chlorophyll-*a* > 10 mg/l

[2]For this analysis, a large bloom is defined by waters having chlorophyll-*a* concentrations ≥10 µg/L

The timing of phytoplankton blooms at stations sampled repeatedly by PSAMP over the past five years (Figure 2-1) show that, in most years, the greatest numbers of blooms occurred in May and June; however, there was considerable inter-annual variability with maximum numbers of blooms also occurring in April, July, and August. Prolonged phytoplankton blooms can have important ecological consequences, because the increased production can drive reductions in the dissolved oxygen available to organisms living at depth. For example, the high number of months in which blooms have occurred in south Hood Canal in recent years may be responsible for lengthening the seasonal period of low dissolved oxygen. Similarly, locations such as Budd Inlet, Penn Cove, Possession Sound, Saratoga Passage, Bellingham Bay, and South Admiralty Inlet, which also are prone to low dissolved oxygen, had blooms in seven or more months of the year.

Harmful algal blooms

Harmful algal blooms (HABs) in Puget Sound are those that can cause Paralytic Shellfish Poisoning (PSP) and Amnesic Shellfish Poisoning (ASP). The region's first recorded PSP incident occurred in June 1793, when four crewmen with Captain Vancouver's expedition became sick and one died shortly after eating shellfish along the central coast of British Columbia. In Puget Sound, the poison that causes PSP is saxitoxin, produced by the dinoflagellate *Alexandrium catenella*. (See Chapter 5, section 4, for additional information on HABs.)

b. Zooplankton

Zooplankton can be divided into microzooplankton and macrozooplankton, based on size. Copepods and crustacean larvae dominate the mircozooplankton of the Central Puget Sound Basin (Hebard 1956); jellyfish, salps, and ctenophores dominate the macroplankton. The latter prey upon copepods and ichthyoplankton (fish larvae) and can be important in controlling the populations of their prey species.

Planktonic food web structure is important to the support of culturally and commercially important fish. The diets of salmon species have been well defined for Puget Sound. Pink and chum salmon move offshore and shift to pelagic prey once they reach a length of 1.9 inches (50 mm) to 2.5 inches (60 mm). Pinks and chums, in turn, fall prey to juvenile coho salmon, steelhead, and sculpins. Juvenile chinook and coho salmon have a larger and more diverse prey spectrum, including terrestrial insects, invertebrate plankton, and epibenthos (organisms that live on or in the sea-floor sediments), and progressing to include juvenile fishes. In turn, these fish fall prey to larger fishes, including sockeye salmon, steelhead, and cutthroat trout (Dexter et al. 1981). Forage fishes, such as herring, sand lance, and smelt, also depend upon zooplankton for food, often forming dense schools at tidal fronts (rip-tides) where plankton becomes concentrated. Larger salmon, dogfish, seabirds, and other predators take advantage of these zones and concentrate the forage fish into tight schools—or bait balls—and feeding frenzies ensue.

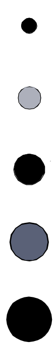
4. Aquatic Vegetation

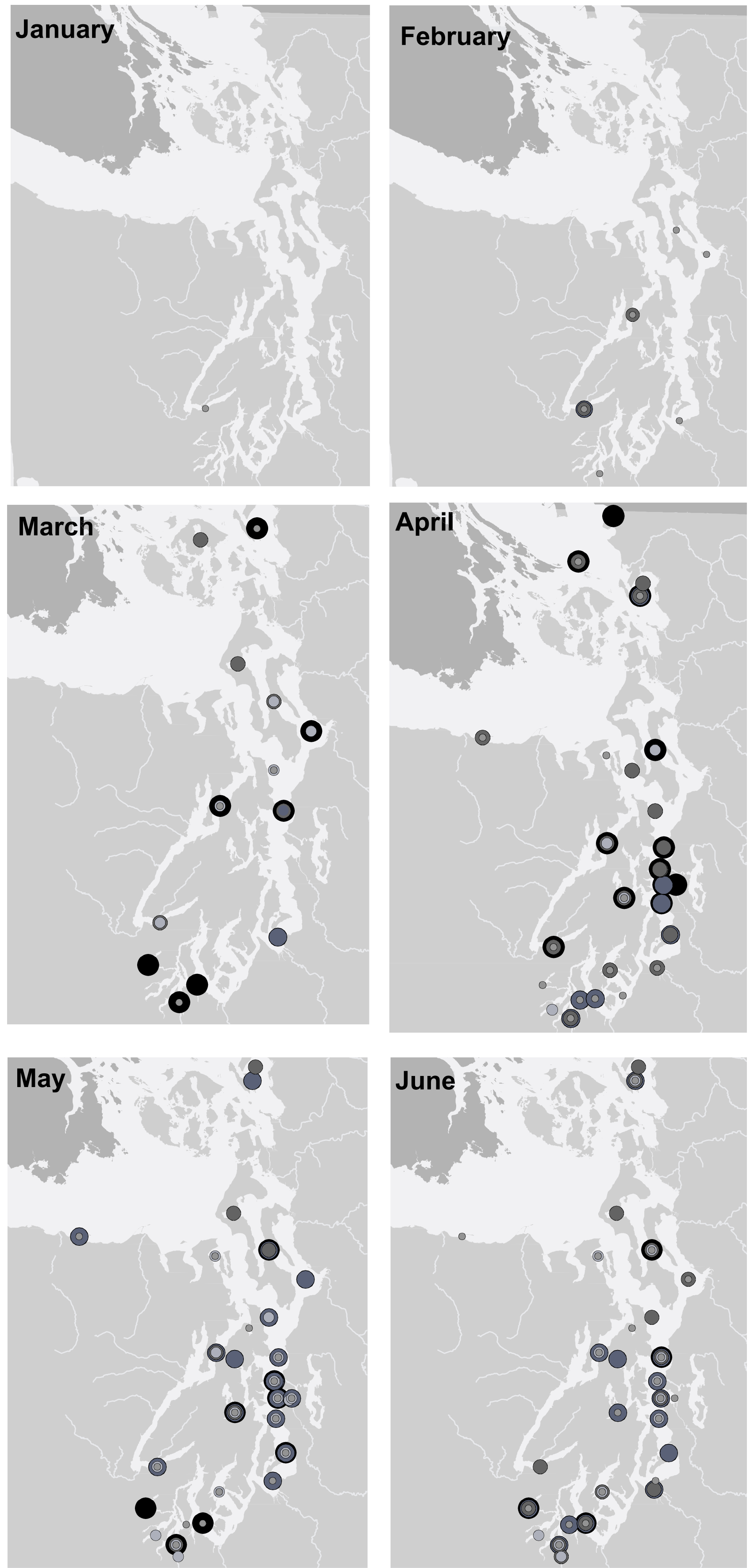
Aquatic vegetation is a key component of the nearshore environment that supports the ecosystem through primary production and by providing habitat to numerous species of fish, invertebrates, birds, and mammals. Puget Sound is home to a diverse assemblage of aquatic plants and algae, each with unique habitat requirements. Major threats to submerged aquatic vegetation include physical disturbance, loss of water clarity, and excessive nutrients. Known to be important ecosystem components that are sensitive to anthropogenic stressors, eelgrass and kelp species are commonly recognized indicators of aquatic vegetation health.

a. Kelp

Kelps are large seaweeds in the Order Laminariales. Twenty-six species of kelp grow along Washington's shorelines, making the state one of the richest sites of kelp diversity in the world (Gabrielson et al. 2000). Kelp beds support commercially and recreationally important fish and invertebrates, as well as marine mammals and birds (Dayton 1985, Duggins et al. 1989). Many factors, both natural and human-caused, affect the extent and composition of these important nearshore habitats (Duggins 1980, Dayton and Tegner 1984, Foster and Schiel

Figure 2-1. Distribution of phytoplankton blooms for Puget Sound stations sampled from 2001-2005. Note that stations are sampled monthly, which is not an adequate interval to capture short-term changes in phytoplankton abundance. The earliest phytoplankton blooms occurred in January (2001), February (2003, 2004), and March (2002, 2005); the latest blooms were observed in November (2004), October (2001, 2002, 2003), and September (2005). All stations with early (January, February) and late (October, November) blooms had low to moderate dissolved organic nitrogen levels, indicating possible nutrient limitation and suggesting that, under appropriate conditions, small inputs of nutrients could induce blooms.
(Source: Ecology)





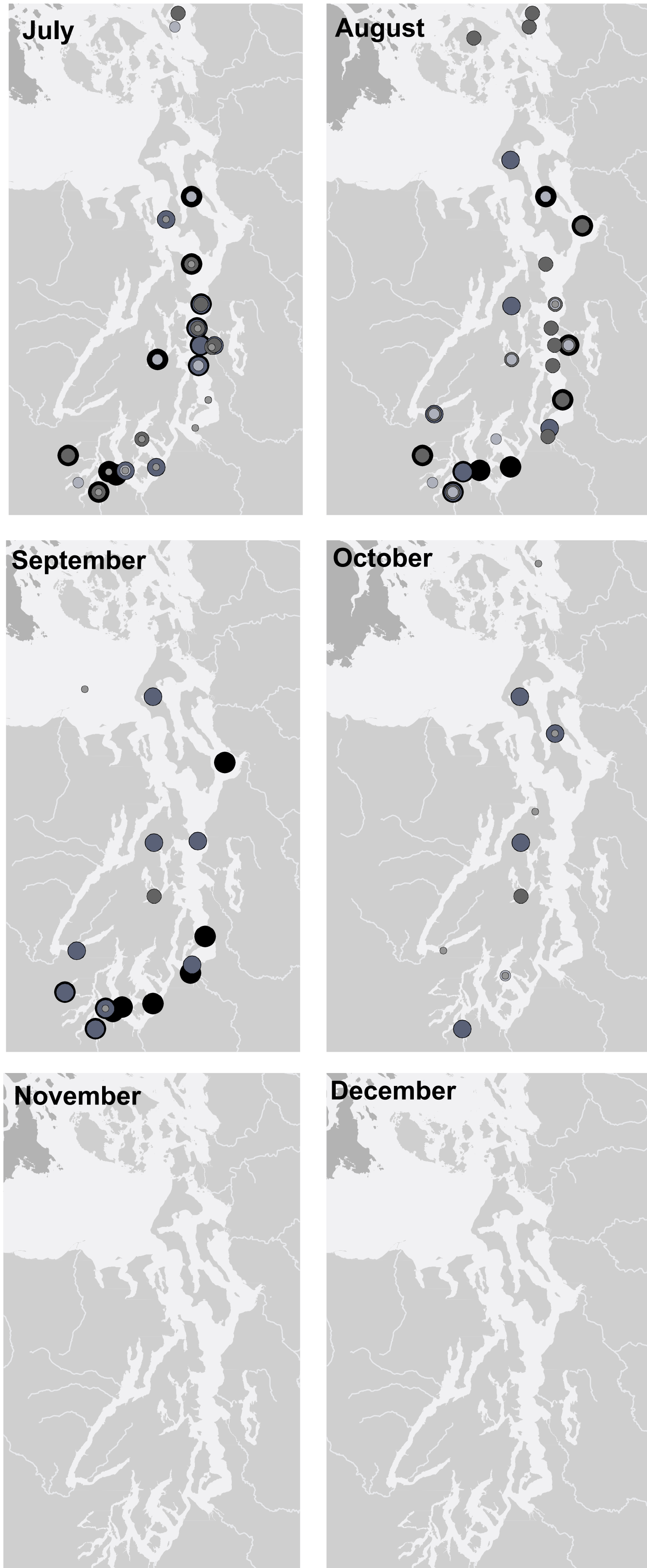
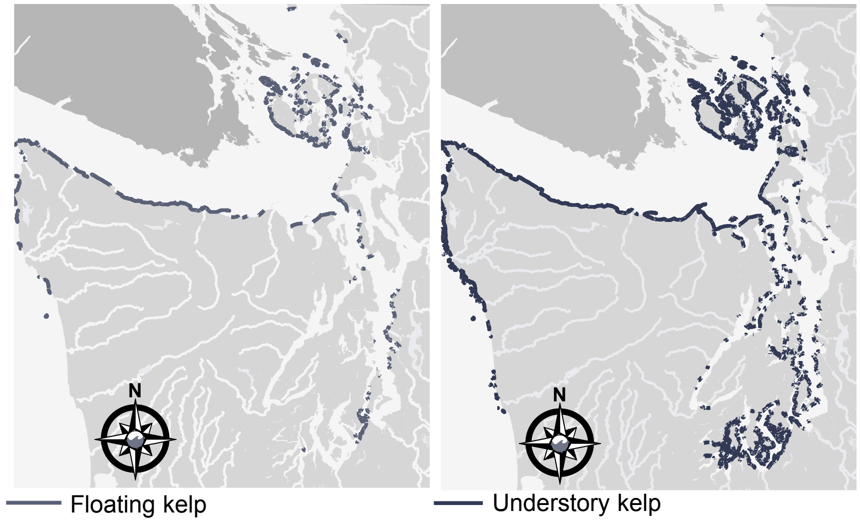

July
August
September
October
November
December

Figure 2-2. The distribution of floating kelp and understory kelp in Washington state. There is a gradient in the occurrence of kelp in Puget Sound due to natural environmental conditions. Kelp is most common in rocky, high-energy environments, with greatest abundance in the San Juan Archipelago and the Strait of Juan de Fuca. Kelp beds gradually decrease in size and frequency in central and southern Puget Sound. Kelp is uncommon in Hood Canal. Understory kelp is more common than floating kelp throughout Washington, with the most notable difference occurring in southern Puget Sound, where understory kelp is found along higher current shorelines with suitable substrate. (Source: DNR)



1985). Kelp species can be grouped by their growth forms: floating kelp produces buoyant bulbs and blades that spread out on the water surface, while understory kelp canopies extend horizontally near the bottom.

PSAMP scientists with the Nearshore Habitat Program of DNR have inventoried floating kelp beds annually (with the exception of 1993) since 1989 along the Strait of Juan de Fuca and the outer coast. Color-infrared photography is used to measure two parameters: canopy area (the area of the water surface covered by stipes, bulbs, and blades) and bed area (including both canopy area and gaps between plants that are less than 82 ft (25m) wide).

Status and Trends

Floating kelp occurs along approximately 11 percent of Washington's saltwater shorelines (Nearshore Habitat Program 2001). There is a gradient in the occurrence of floating kelp in Puget Sound due to natural environmental conditions (Figure 2-2). Kelp is most common in rocky, high-energy environments, with greatest abundance in the San Juan Archipelago and the Strait of Juan de Fuca. Kelp beds gradually decrease in size and frequency in central and southern Puget Sound. Kelp is uncommon in Hood Canal.

Bull kelp (*Nereocystis luethkeana)* is the primary floating kelp species found throughout Puget Sound. The southernmost persistent bull kelp bed is located off Squaxin Island, near Olympia. Along the western Strait of Juan de Fuca and outer coast, giant kelp (*Macrocystis integrifolia*) also occurs. Giant kelp forms extensive surface canopies that are either intermixed with bull kelp or grow closer to shore than bull kelp. Bull kelp is generally more abundant than giant kelp in the Strait of Juan de Fuca, in terms of total bed area. However, giant kelp forms denser beds. While both species are fairly variable from year-to-year, bull kelp exhibits higher inter-annual variation.

High year-to-year variability is common in kelp beds (Dayton 1985, Dayton and Tegner 1984, Grove et al. 2002). Along the Strait of Juan de Fuca, bed area extent was lowest in 1989 (1,911 hectares, or 4,722 acres) and greatest in 2000 (4,788 hectares, or 11,832 acres). Despite high year-to-year variability, significant trends in floating kelp are apparent along the Strait of Juan de Fuca and the outer coast (Berry et al. 2005). In order to identify areas of change at a high resolution, data were analyzed for trends at the scale of shoreline sections ranging from 3-9 miles

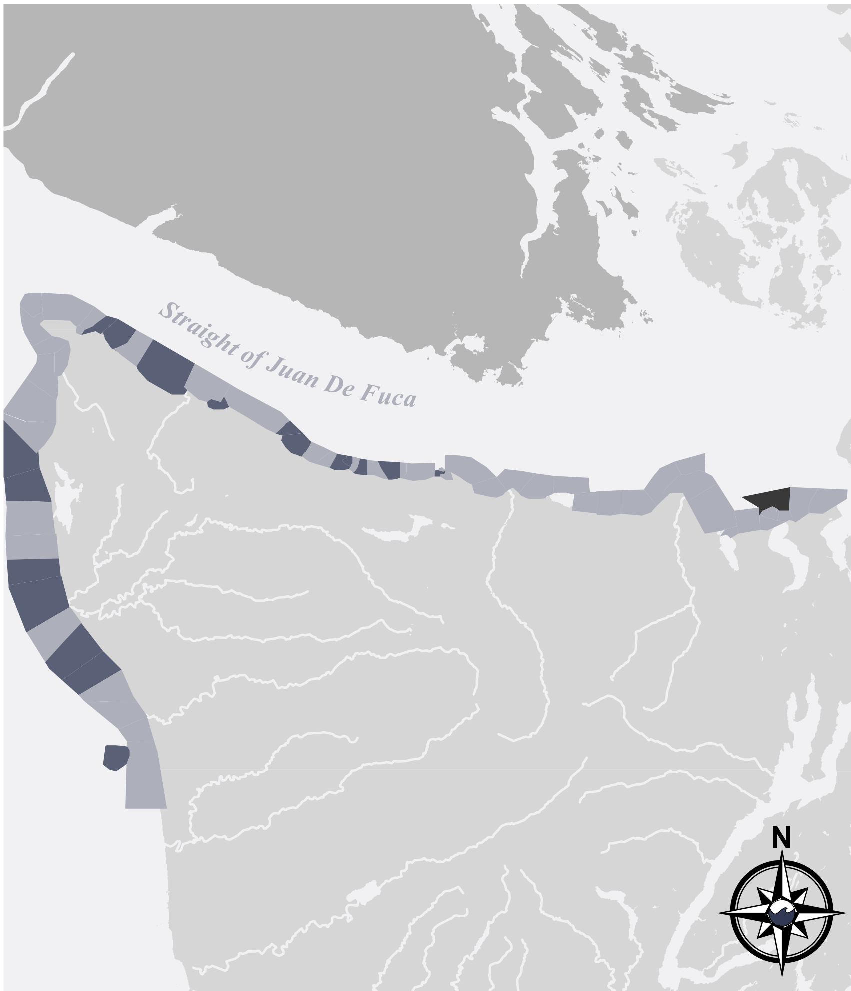


Figure 2-3. Trends in kelp canopy in Washington waters. Significant trends in kelp canopy area within shoreline sections, based on annual surveys between 1989 and 2004. Increasing trends are confined to the western Strait of Juan de Fuca and the outer coast. The only declining trend was found near Protection Island in the eastern Strait.
(Source: DNR)

(5-15 km), with boundaries defined by geomorphological features[3]. Canopy area increased significantly in 18 sections, decreased significantly in one section, and did not change significantly in 47 sections (Figure 2-3). In some areas, significant increases occurred in two adjacent sections, suggesting that patterns of change might be occurring over larger areas than sections. Of two parameters studied—canopy and bed area—the pattern of trends were similar, but with more significant trends observed in canopy area. This finding suggests that canopy area is the more sensitive of the two parameters.

Multiple factors could be contributing to observed trends in floating kelp beds. Sea otter population growth and range expansion could have indirectly increased kelp communities by depleting the sea urchin populations that feed on kelp (Estes et al. 1978, Duggins 1980). Sea otters were re-introduced to Washington state in 1969 and 1970, after being extirpated in the early 1900s by hunting, and populations have grown an average of eight percent annually since reintroduction (Lance 2004). Sea otters were initially limited to the outer coast around Destruction Island, then gradually expanded into the western Strait of Juan de Fuca in 1995, with populations reported as far east as Pillar Point.

Other factors influencing kelp abundance and distribution include high water temperatures and low nutrient concentrations associated with El Niño conditions, which are known to cause short-term losses (Foster 1985). Pacific Decadal

[3]For this analysis, $p<.01$

Oscillations (PDOs) could be driving changes over longer time periods. Increased fine sediment from rivers or substrate movement influences the amount of available habitat for attachment. Increased sediment in the water causes reduction of light available to fuel growth. Competitive interactions among algal species can lead to a community shift from high disturbance species, such as bull kelp, to lower disturbance species, including giant kelp and stalked kelp (*Pterygophora californica*) (Dayton 1985).

Human harvest of sea urchins could have indirectly affected kelp canopy area by decreasing populations of these herbivores. Sea urchins are harvested along the Strait of Juan de Fuca portion of the floating kelp study area but not the outer coast (M. Ullrich, WDFW, pers. comm.) Peak landings occurred between 1988 and 1992, and harvest levels have decreased since then, with closures due to depleted stocks in portions of the Strait of Juan de Fuca. (For more information on sea urchins, see Section 5c of this chapter.)

Impacts to the Ecosystem

Because of their large biomass and rapid growth rates, kelp beds form one of the world's most productive habitats (Mann 1982). Kelp supports the food web through direct consumption by grazers, consumption of drift material by benthic herbivores, consumption of particulate detritus by suspension feeders, and utilization of organic carbon by a wide range of organisms (Duggins 1987).

Changes in kelp abundance and distribution affect habitat availability for valued species. Kelp beds form structurally complex, three-dimensional habitats that are used by invertebrates, fish, birds, and mammals. Juvenile rockfishes associate with floating kelps, and this habitat may be an important stepping-stone in the life history of splitnose and tiger rockfishes (Buckley 1997). Also, massive mats of drift kelp can be found at all depths of Puget Sound (W. Palsson, WDFW, pers. comm.). This material provides substrate for benthic and epibenthic organisms, which is believed to lead to increases in the abundance, biomass, and diversity of other nearshore organisms (Duggins 1987). As a result of the important role kelp plays, widespread losses of kelp beds would have repercussions for the broader Puget Sound marine system.

b. Eelgrass

Eelgrass (*Zostera marina*) is the dominant seagrass in Washington. It provides habitat, supports complex food webs, promotes biodiversity, and improves water quality throughout Puget Sound (Phillips 1984, Thom et al. 1998, Hemminga and Duarte 2000, Green and Short 2003). It has been documented as habitat for salmon, spawning grounds for herring, and a food resource for black brant and other waterfowl (Thayer and Phillips 1977, Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995). In addition, eelgrass provides a source of carbon in nearshore habitats (Simenstad and Wissmar 1985, Kentula and McIntire 1986), stabilizes sediments (Fonseca 1996), and, because of its sensitivity to environmental degradation, has been used as an estuarine health indicator in many parts of the world (Dennison et al. 1993, Hemminga and Duarte 2000, Lee et al. 2004, Krause-Jensen et al. 2005). Eelgrass grows in fringing beds along much of Puget Sound's shoreline and also grows commonly on flats, in large shallow embayments, and along small pocket beaches.

In 2000, as part of PSAMP, scientists with the Nearshore Habitat Program of DNR initiated the Submerged Vegetation Monitoring Project (SVMP) to assess spatial patterns and temporal trends in eelgrass habitat (Berry et al. 2003). Because no single parameter adequately describes eelgrass bed condition, several parameters

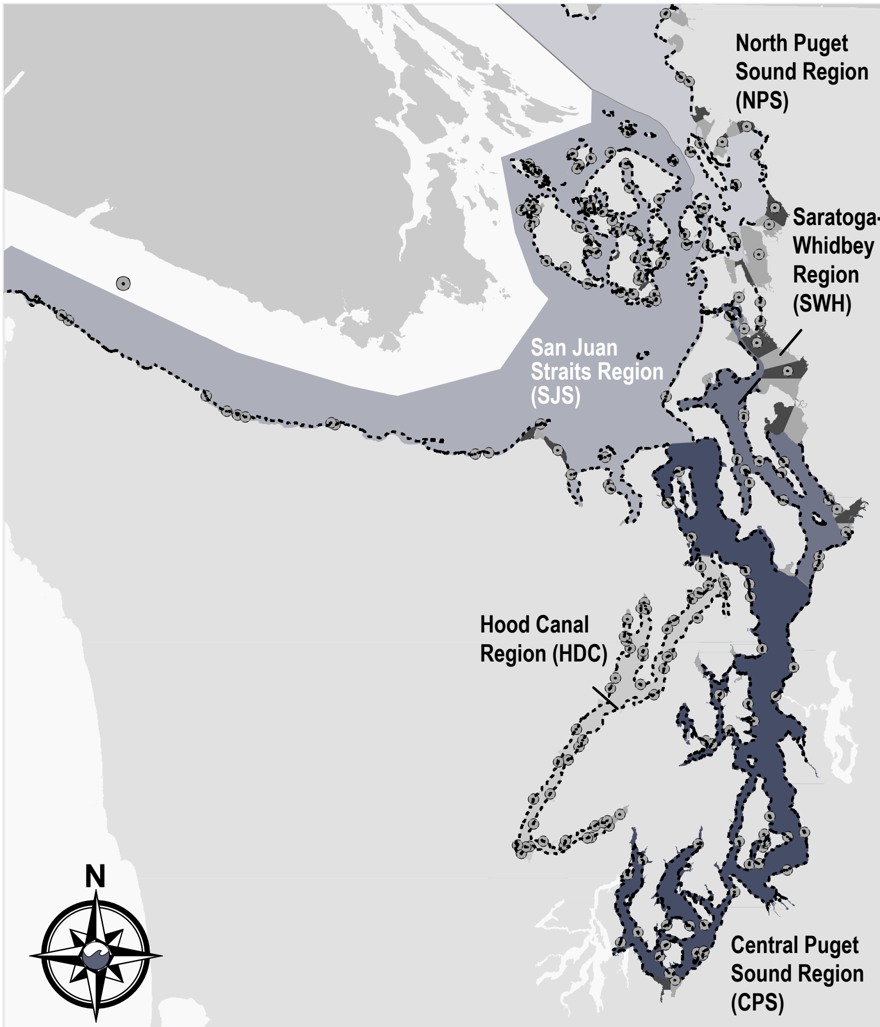
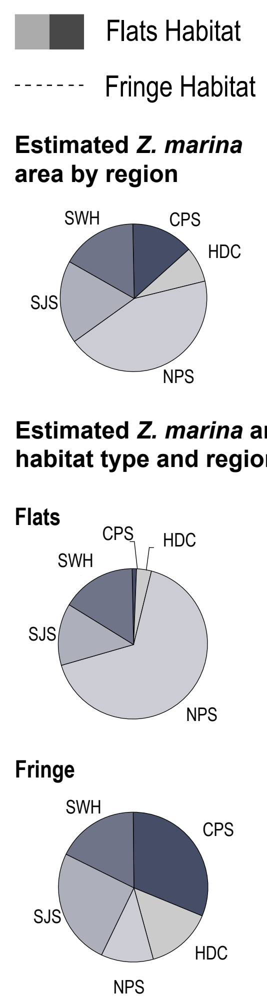


Figure 2-4. Estimated eelgrass *Z. Marina* in Puget Sound. All sites sampled by the SVMP, 2000-2005, and the five regions that make up the greater Puget Sound study area. Each 3,000-ft (approx. 1,000 m) linear segment represents a site. The pie charts show the 2005 estimated distribution of eelgrass area by region, both overall and within the flats and fringe habitats. (Two colors of shading are used to distinguish adjacent discrete sites.) Eelgrass is not evenly distributed across Puget Sound. The greatest portion is in the NPS region, which is dominated by eelgrass in flats sites. In this region, approximately 27 percent of the total eelgrass in Puget Sound is found within Padilla Bay and Samish Bay. In contrast, CPS is dominated by eelgrass in fringe sites; in the other regions, the eelgrass is more evenly mixed among flats and fringe sites. (Source: DNR)



were monitored: eelgrass area (number of square meters with seagrass growing on it), maximum and minimum depth, and patchiness of beds (both fringe and flats). At the current level of effort, the monitoring program will be able to detect as little as a 20 percent change in Soundwide eelgrass abundance over a 10-year monitoring period. The SVMP also monitors changes at five subregions within greater Puget Sound and at individual sites (Figure 2-4).

Status and Trends

In 2005, there were approximately 50,400 acres of eelgrass in Puget Sound, evenly distributed between flats and fringe habitat types (Gaeckle et al. in prep). However, eelgrass is not evenly distributed across the Sound; results in 2005 confirm earlier reports that 27 percent of the eelgrass in Puget Sound grows in Padilla Bay and Samish Bay (Dowty et al. 2005). This indicates that the extensive eelgrass meadows in these two bays provide unique habitat on a scale that is not replicated elsewhere within greater Puget Sound.

In 2005, the SVMP completed a study of the spatial differences in eelgrass depth distribution throughout Puget Sound and created depth profiles for the habitat types (flats and fringes) on a regional and Soundwide basis[4] (Figure 2-5) (Selleck et al. 2005). The profiles clearly show that eelgrass in Puget Sound is predominantly subtidal and that there are strong regional differences. The

[4]Sample sites are randomly selected from potential flats and fringe habitat.

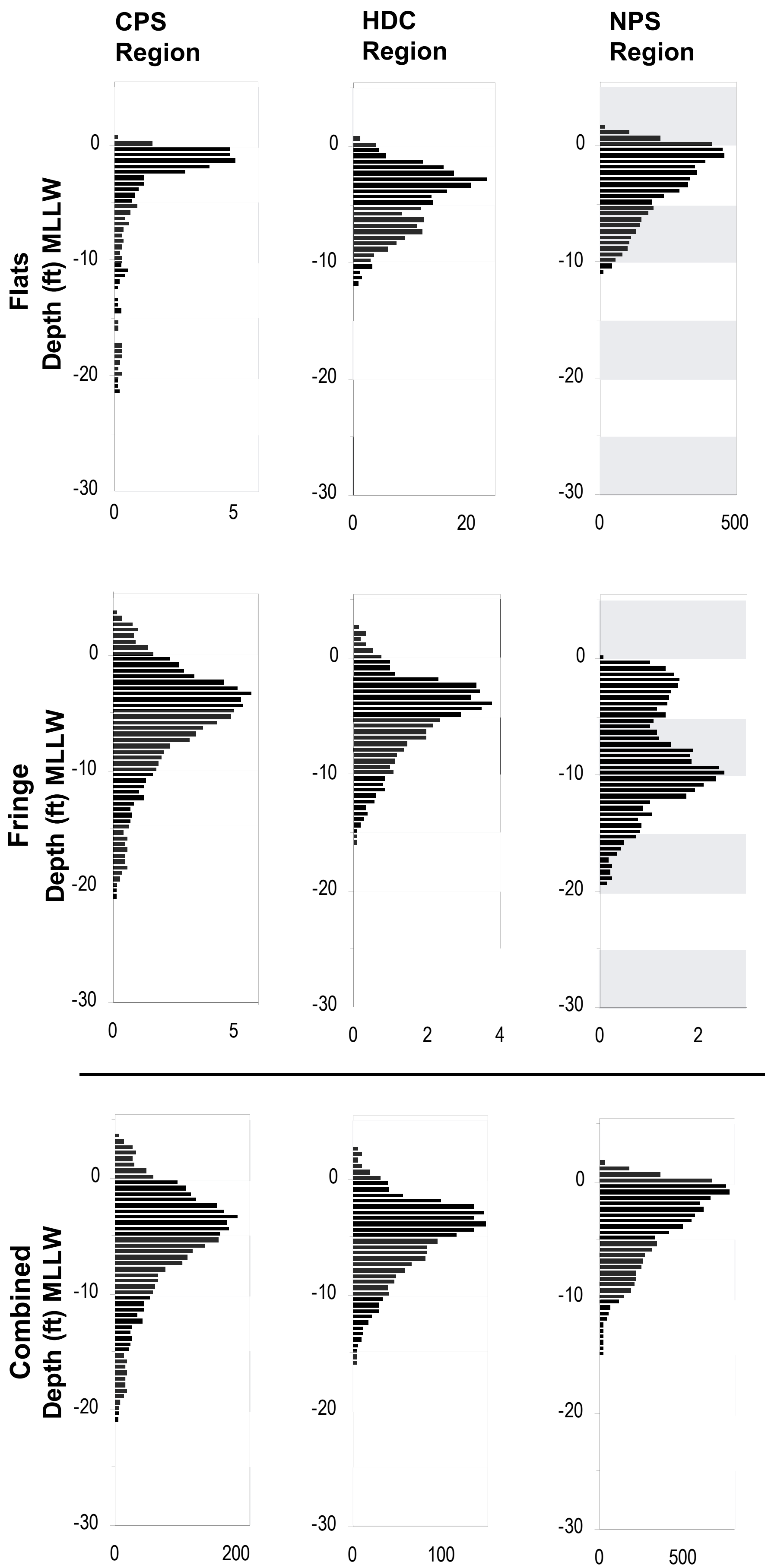
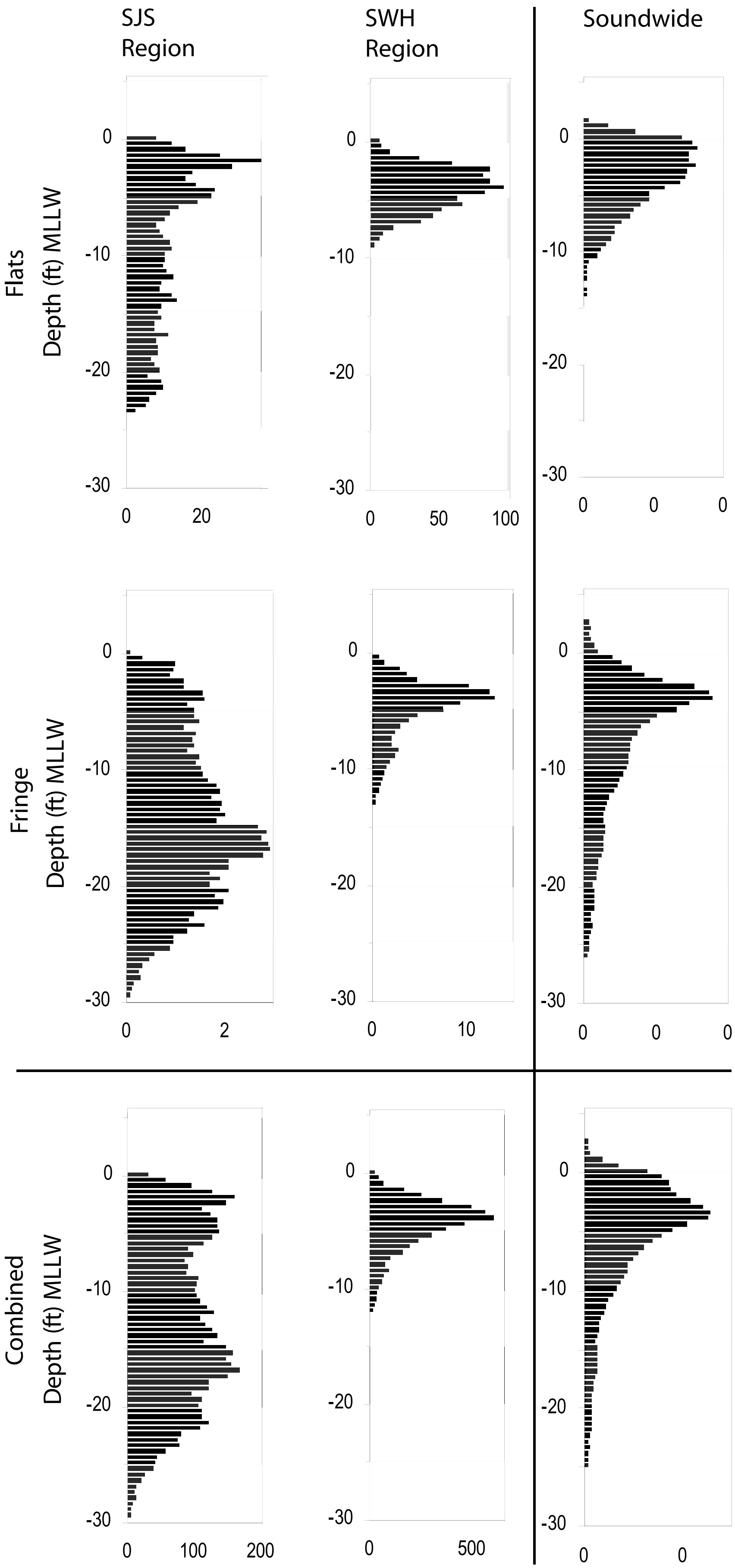


Figure 2-5. Eelgrass depth in Puget Sound. Depth profiles of eelgrass aggregated by the SVMP regions—flats, fringe habitat and combined flats and fringe habitat—based on data from 2002–2004, relative to Mean Lower Low Water. These profiles varied greatly among regions, flats, and fringe habitat types, as well as between individual sites. Overall, eelgrass in Puget Sound is predominantly subtidal and tends to grow shallower at flats sites and deeper at fringe sites concurring with differences in depth profiles of the available habitat in these areas. The sensitivity of eelgrass to water clarity is clearly seen in the deeper eelgrass in the SJS region, where clarity tends to be greater. Note: eelgrass was observed at depths greater than 30 ft (9 m) in the SJS region; however, such data do not appear in the depth profiles because of the small quantity of these observations and, therefore, are not included in the figure.
(Source: DNR)

Eelgrass Study Regions

CPS	Central Puget Sound
HDC	Hood Canal
NPS	North Puget Sound
SJS	San Juan Straits
SWH	Saratoga Whidbey


SJS Region
SWH Region
Soundwide
Flats
Fringe
Combined
Depth (ft) MLLW
0
-10
-20
-30
20
50
100
2
10
200
500

greatest depths with eelgrass were observed in the San Juan Straits (SJS) region, an indication of greater quality in this area because of extensive ocean flushing and high water clarity. Overall, the maximum depth of eelgrass at sampled sites ranged from 5.9 feet (1.8 m) above Mean Lower Low Water (the long-term average depth of the lowest tide per day) to -39 feet (-11.9 m) (Dowty et al. 2005, Selleck et al. 2005). The maximum depth of eelgrass is dependent not only on water clarity (indication of available light) but also on nutrient and dissolved oxygen concentrations (Greve and Krause-Jensen 2005).

On a Soundwide scale, there has been no evidence of a trend in eelgrass area (Dowty et al. 2005). At a smaller scale, yearly estimates of eelgrass area change within the Hood Canal region (HDC) indicate four consecutive years of decline. This estimated loss is of particular concern, given the current scientific and political focus on the conditions of low dissolved oxygen in Hood Canal (Newton and Hannafious 2006). Three other regions—North Puget Sound (NPS), Saratoga Whidbey Region (SWH), and San Juan Straits (SJS)—were variable and did not present evidence of change. In Central Puget Sound (CPS), eelgrass area declined over the last two years, but these declines were not statistically significant (Figure 2-6).

Focus Areas

In 2004, DNR scientists initiated a focus-area effort that involves more intensive sampling within one of the five SVMP regions each year. The study rotates through different focus areas on a five-year schedule in an effort to improve status estimates on regional scales and to better identify patterns of decline within regions (Berry et al. 2003). In 2004, focus-area sampling started in the San Juan Archipelago area of the SJS region. In 2005, the focus-area sampling was directed to the HDC region, to help address the relationship between the observed low dissolved oxygen and eelgrass health and status (Newton and Hannafious 2006). Change analysis within each focus area will be completed after a region is sampled again in five years.

Non-native Seagrass

The presence and widespread distribution of the introduced species *Zostera japonica* demonstrates its opportunistic behavior and generates questions as to its ecological function and how it competes for resources with other eelgrass (Figure 2-7). (Harrison 1976) Dwarf eelgrass, native to the western Pacific and first observed on the Pacific coast of North America in 1957, occupies higher intertidal areas compared to eelgrass, but there are areas where the range of these two species overlaps. Presently, there is a dwarf eelgrass eradication program in Humboldt Bay, California, and, although the presence of this species has provoked numerous debates in Washington, there are currently no efforts to remove it from Puget Sound.

Impacts to the Ecosystem

There are numerous anthropogenic and environmental factors that cause widespread seagrass loss (Short et al. 1991, Short and Wyllie-Echeverria 1996, Short and Neckles 1999, Duarte 2002). The loss of seagrass in Puget Sound could lead to a significant decline of marine and estuarine biodiversity, including a vast amount of associated flora (epiphytic algae) and fauna that coexist with seagrass. In addition, many organisms utilize seagrass for shelter or protection, as foraging grounds, or as habitat for migration purposes (Thayer and Phillips 1977, Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995, Green and Short 2003). Seagrass dampens wave and current energies and its loss would lead to increased shoreline erosion (Fonseca 1996). Its ability to support a productive nearshore ecosystem through nutrient regeneration and filtration (Hemminga et al. 1999)

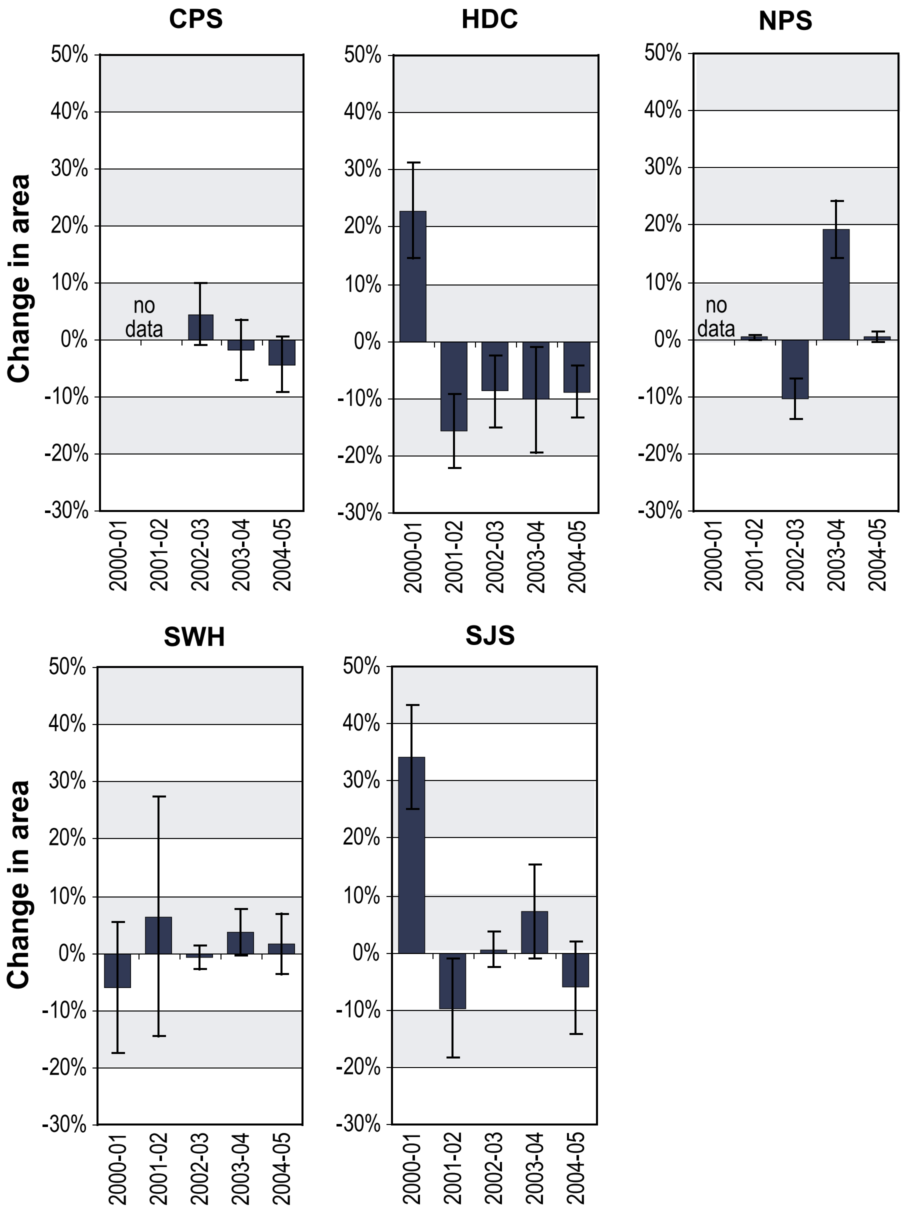


Figure 2-6. Estimated annual change in eelgrass in Puget Sound, 2000 to 2005. Throughout Puget Sound, there has been no evidence of seagrass decline. At a smaller scale, yearly eelgrass estimates in three of the five regions—NPS, SWH, and SJS—were variable and did not present evidence of persistent change. In CPS, seagrass area declined over the last two years, but these declines were not statistically significant. The pattern of eelgrass area change within HDC, a region with significant seagrass decline, has continued for a fourth consecutive year. (Source: DNR)

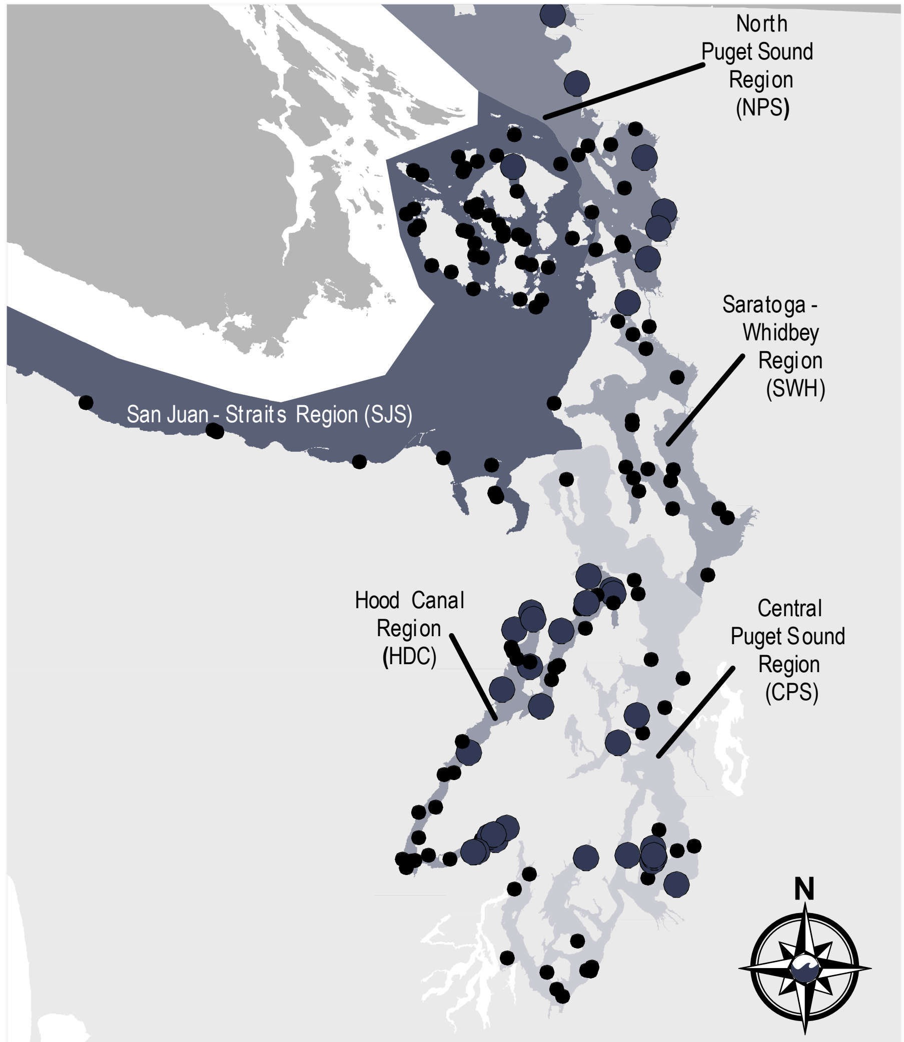
and oxygen production (Vermaat and Verhagen 1996) would also be lost. The implications of seagrass loss could have significant consequences to biodiversity, productivity, and ecological stability throughout Puget Sound.

d. Eelgrass and Climate Variation in Puget Sound

Long-term monitoring indicates that the abundance and distribution of eelgrass can vary significantly from year to year. Emerging evidence shows a potential linkage between climate and variations in eelgrass abundance. In particular, massive (700 percent) changes in eelgrass abundance in Willapa Bay corresponded with the El Niño - La Niña event at the end of the 1990s (Thom et al. 2003). The production of flowering shoots also increased substantially during the El Niño - La Niña transition. Puget Sound experienced two extreme climate events in the latter half of the 20th century (1982-1983, 1997-1998) that were likely to have affected eelgrass (Thom and Albright 1990, Thom et al. 2003). Data from these events can help scientists understand the magnitude and perhaps the mechanisms responsible for variations in eelgrass abundance and distribution.

Figure 2-7. The distribution of non-native dwarf eelgrass *(z. japonica)* at the 2004 and 2005 SVMP sampling sites. (Source: DNR)

- *Z. japonica* present
- *Z. japonica* not present



Suspected climate-related factors driving seagrass variation are extremes in temperature and changes in mean sea level. Temperature affects rates of eelgrass photosynthesis and respiration. The optimal temperature for eelgrass growth is within a very narrow range of 41-46 degrees F (5-8 degrees C) (Thom 1995). This range of temperatures is typical of winter, but light tends to be lower and, therefore, growth is reduced. Conversely, improved light conditions in spring and summer can coincide with warmer temperatures, which impede growth. The optimal mix of temperature and light conditions occurs within a narrow period, suggesting that eelgrass can be significantly affected by variations in climate.

Mean sea level is dramatically affected by climate, with higher sea levels (up to about 11.8 inches, or 30 cm) during strong El Niño conditions, and lower levels (- 7.9 inches, or -20 cm) during strong La Niña conditions. Scientists predict that sea-level rise may benefit shallower, flat-dwelling eelgrass by reducing impacts of desiccation and heat stress, because the plants are covered by water for longer periods. However, deeper-dwelling eelgrass showed reduced abundances during El Niño conditions (Thom et al. 2003), attributed to turbidity and shallower light penetration in the water column.

FOCUS STUDY

Eelgrass declines in the San Juan Archipelago

An estimated total of 83 acres (34 hectares) of eelgrass disappeared from small embayments in the San Juan Archipelago between 1995 and 2004 (Figure 2-8; Table 2-2). Westcott Bay is one of several shallow embayments within the San Juan Archipelago and, because population loss was both rapid and complete at this site, the first phase of the ensuing research plan was to determine if losses might be occurring within other shallow embayments in the archipelago. An interdisciplinary team of scientists from the University of Washington, DNR, Ecology, Coastal and Marine Geology Branch of USGS, the University of South Alabama, and Friends of the San Juans set out to determine the causes of this decline.

Beginning in 2004, researchers examined historical aerial photos for the presence of eelgrass. For this analysis, 11 shallow embayments were selected for further evaluation. Selection was based on the size of the embayment, the availability of quality aerial photo data for the period when loss was observed in Westcott Bay, and geographic distribution within the archipelago. Scientists discovered that aggregate losses totaling 251.8 acres (102 hectares) occurred between 1995 and 2001, with eight of the 11 locations experiencing declines and eelgrass losses occurring in eight of the 11 survey locations. This historical data were compared with data collected in 2003; the comparison showed that, while recovery took place at three sites, the trend of decline detected in 2001 continued in six locations, with two additional sites—Garrison Bay and Nelson Bay—also experiencing local extinctions. Eelgrass acreage at a fourth site, the eastern reach of Mitchell Bay, increased between 1995 and 2001 but was completely gone in 2004.

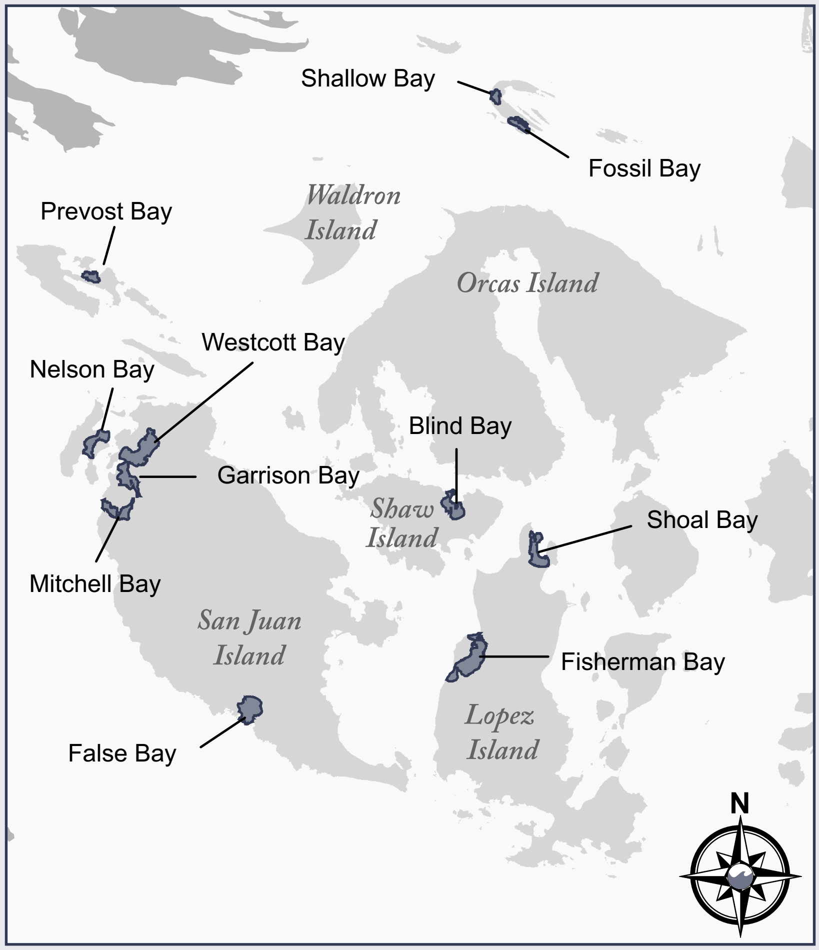


Figure 2-8. Location of eelgrass loss in the San Juan Archipelago. The location of sites selected for retrospective analysis following the sudden loss of eelgrass within Westcott Bay in the San Juan Archipelago between 1995-2004. (Source: DNR)

Location	1995	2001	2003	2004	2003/04
Blind Bay	14.8	5.2	n.d.	4.9	4.9
False Bay	9.4	4.0	n.d.	10.1	10.1
Fisherman Bay	34.0	29.2	23.6	n.d.	23.7
Fossil Bay	12.8	11.4	n.d.	4.4	4.4
Garrison Bay	5.2	5.2	0	.n.d.	0
Mitchell Bay	2.5	3.5	n.d.	0	0
Nelson Bay	17.8	5.4	n.d	0	0
Prevost Harbor	8.9	9.4	4.9	n.d.	4.9
Shallow Bay	7.6	6.4	12.8	n.d.	12.8
Shoal Bay	6.4	4.2	n.d.	7.9	7.9
Westcott Bay	32.1	16.3	0	n.d	0
Total (acres)	**151.6**	**100.2**	**40.9**	**27.3**	**68.7**

Table 2-2 Comparison of eelgrass acreage estimates at 11 sites within San Juan County between 1995 and 2004. There has been a steady decline in total acreage during this period, with Westcott Bay and Fisherman Bay experiencing the largest losses. (n.d.= no data available) (Source: DNR)

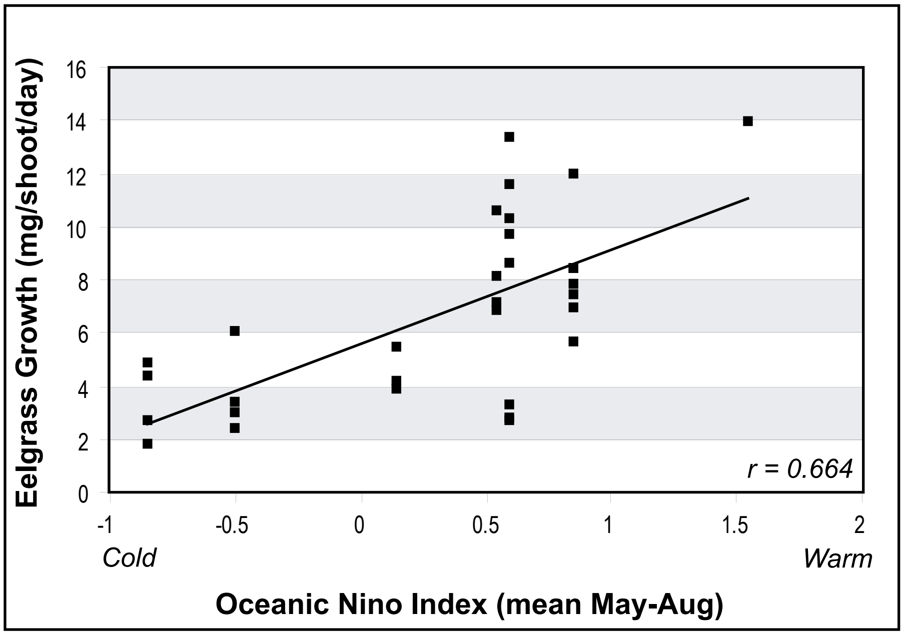


Figure 2-9. Eelgrass growth and climate. The growth rate of eelgrass in 10 summers between 1991 and 2005 at Sequim Bay was strongly correlated with the Oceanic Niño Index, suggesting there may be a climate-related cause for differing growth patterns. During colder years the plants grew slower, and during warmer years the plants grew faster. The fastest growth rates were measured in the summer of 1997, at the start of the strongest El Niño event in the 20th century. The values are means of growth for at least 30 replicate plants. Three to four growth rate experiments were conducted in each of the 10 years. (Source: PNNL)

Status and Trends

During 10 summers between 1991 and 2005, eelgrass growth rates near the mouth of Sequim Bay varied substantially. The fastest growth rate ever recorded was in 1997 at the start of the El Niño period. Growth rates of eelgrass correlate with the PDO Index and the Oceanic Niño Index (Figure 2-9). The PDO is a measure of conditions in the Northeast Pacific Ocean and can be used to explain variations in plankton and salmonid survival in the eastern North Pacific Ocean.

Annual studies of subtidal eelgrass density near the Clinton ferry terminal on Whidbey Island show a strong correlation with El Niño conditions, with greatest densities occurring during neutral (average) conditions. There is some evidence that links climate to eelgrass abundance, but further study is needed to verify mechanisms and the multiple factors that contribute to eelgrass variation. Climate change combined with sea-level rise may result in eelgrass losses at lower depths and expansions at the upper limits of eelgrass' present distribution.

Impacts to the Ecosystem

Eelgrass meadows perform several important functions to the ecosystem. In particular, eelgrass provides a source of habitat and organic matter to the food web. Anecdotal observations from researchers in Alaska indicate that during the 1997-1998 El Niño event, brant populations along the coast suffered because of reductions in the amount of eelgrass.

5. Intertidal Biota

Intertidal biotic communities are comprised of the invertebrates, seaweeds, and plants living on shorelines that are exposed during low tides and underwater during high tides. These communities are important for their biodiversity values and for their roles in ecosystem processes. Common intertidal biota on Puget Sound's beaches include well-known species, such as oysters, clams, crabs, sea stars, and snails, along with lesser known species, such as polychaetes, amphipods, and algae. Shorebirds, marine bird, fish, and mammals depend upon many of these organisms for food, and humans utilize shellfish beds for ceremonial, recreational, and aquacultural opportunities.

Intertidal organisms are sensitive to environmental changes and may serve as indicators of environmental health (Warwick and Clarke 1993). Because the intertidal zone lies between the marine and terrestrial environments, organisms living in this zone are affected by a complex array of stressors from both land (when exposed) and sea (when immersed). In Puget Sound and other estuaries, intertidal organisms contend on daily and seasonal bases with highly fluctuating environmental gradients, especially in salinity and temperature. In addition, organisms in these ecosystems must survive, or may succumb to changes in water quality and sediment quality or alterations to habitats caused by development.

a. Intertidal Biotic Communities

DNR's Nearshore Habitat Program and the University of Washington's Department of Biology have monitored intertidal communities in the South and Central Basins of Puget Sound since 1997. Scientists sample epibiota (organisms on the surface of the sediment) and infauna (organisms that burrow within the sediment) in the lower intertidal zone of pebble/sand beaches that share similar geomorphological characteristics. The extensive data set demonstrates a strong coupling between the nearshore waters of the Sound, the physical environment on the beach, and the resident intertidal biotic communities (Schoch and Dethier 1997, 1999, 2001, Dethier and Schoch 2000, Dethier 2005). It also describes large-scale gradients throughout Puget Sound in the biota of pebble beaches (the most common beach type in the Sound). The data are now sufficiently extensive to reveal ecologically significant differences among beaches.

Status and Trends

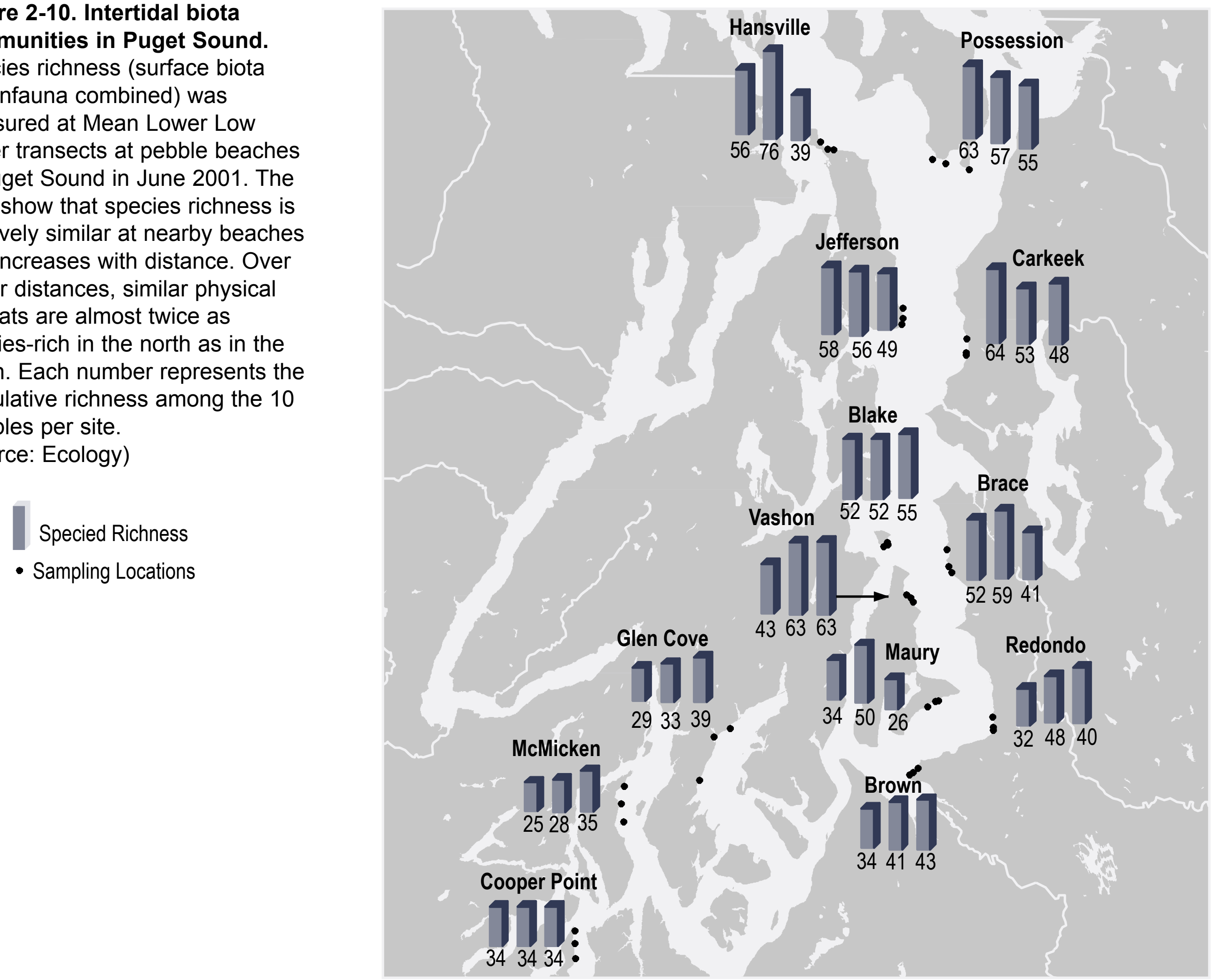
Intertidal benthic communities in pebble/sand beaches of south and central Puget Sound show a striking, temporally consistent pattern in species richness in both surface- and sediment-dwelling organisms (Dethier and Schoch 2005). Biological communities in Puget Sound are consistent among beaches that share similar physical characteristics and are within several kilometers of each other, but show gradual differentiation at increasing distances, especially from south to north (along latitudinal gradients). Over larger distances, similar physical habitats are almost twice as species-rich in the north as in the south (Figure 2-10). Similar patterns can be seen in data collected from 1999 through 2005; however, in those years, fewer sites were sampled. Higher richness in the northern samples parallels other estuarine studies that find the greatest benthic diversity in areas near the mouths of estuaries, where salinities and temperatures tend to be the least variable (and most marine), wave action is highest, turbidity and sedimentation are lowest, and water residence time is the lowest. Any or all of these factors may affect observed trends in the abundance of biota in Puget Sound, although the Central Basin is oceanographically well-mixed, compared with many estuaries.

Intertidal bivalve populations in Puget Sound on public tidelands are generally healthy and stable. Native littleneck clam stocks along Port Susan and Saratoga Pass beaches are an exception. These clams experienced a large mortality event in 2001 that appeared to affect only this species. Interestingly, during this same time period, butter clams in Port Susan and Saratoga Pass have increased. Manila clam populations on several public beaches in Hood Canal are still recovering from a severe winter kill in 2002, in which cold temperatures killed up to 33 percent of the population. Low dissolved oxygen problems in Hood Canal, however, have apparently had little or no impact on intertidal bivalves to date. Annual surveys on public tidelands in the Potlatch area have shown little change in clam biomass, for example.

Eelgrass as carbon sink in Puget Sound?

Studies are being conducted to determine the role seagrass could play in carbon dioxide sequestering (uptake and storage). Laboratory experiments showed that carbon dioxide can stimulate eelgrass growth on the order of 250 percent (Thom 1996). To date, however, there is no way of predicting the effect on Puget Sound eelgrass of rising CO2 levels in the atmosphere.

Figure 2-10. Intertidal biota communities in Puget Sound. Species richness (surface biota and infauna combined) was measured at Mean Lower Low Water transects at pebble beaches in Puget Sound in June 2001. The data show that species richness is relatively similar at nearby beaches and increases with distance. Over larger distances, similar physical habitats are almost twice as species-rich in the north as in the south. Each number represents the cumulative richness among the 10 samples per site.
(Source: Ecology)



Impacts to the Ecosystem

Beaches form the interface between terrestrial and marine ecosystems and are vulnerable to human impacts on both ecosystems. Degradation of intertidal areas can result from a wide variety of human-induced causes, including changes in water quality, losses or unnatural increases in sediment supply, overharvesting of native shoreline organisms, introduction of invasive species, and shoreline development. Such changes can kill intertidal organisms directly (e.g., Olympia oysters poisoned by pulp mill waste) or indirectly (e.g., shoreline armoring causing the removal of fine sediments from beaches, leading to the loss of habitat for clams). Although intertidal biota monitoring does not assess water quality or other direct impacts, it serves as an indicator of the effects of environmental degradation, by detecting substantial changes to the communities living in and on a beach.

6. Subtidal Biota

The subtidal zone refers to shallow waters below the low tide mark. Common subtidal species include worms, crabs, clams, sea urchins, and sea cucumbers. The once-familiar pinto abalone (*Haliotis kamtschatkana*) has undergone dramatic declines during the past two decades. Many species form habitat or are preyed upon by other invertebrates and fish, thus becoming important components of the food web. A wide range of subtidal species is monitored through PSAMP as part of the characterization of marine sediments for determining the health of Puget Sound.

a. Hood Canal Invertebrates

Episodes of low dissolved oxygen in Hood Canal have impacted populations of invertebrates living in Hood Canal, both recently and historically. Invertebrate kills and movement of organisms from deep to shallow waters have been observed and recorded by citizens and scientists. Less is known about the effects of these low dissolved oxygen events on the communities of microscopic invertebrates that live within the sediments of Hood Canal. These organisms are important parts of the food web, supporting populations of bottom-feeding fish and macroinvertebrates.

As part of PSAMP, sediment and near-bottom water samples were collected from 30 stations along the length of Hood Canal in June 2004. Sediment samples were analyzed for grain size, total organic carbon (TOC), toxicity, chemical contaminants, and benthic infaunal community composition. Dissolved oxygen (DO) levels were measured in the water samples. Values were mapped to determine patterns of each variable throughout the canal, and analyses were conducted to determine the relationships between the measures.

Status and Trends

Measures of toxicity and chemical contamination were very low in the Hood Canal sediment samples and not correlated with benthic infaunal indices (described in detail in Long et al. in prep.). Measures of sediment grain size (percent fines) and TOC, near-bottom water DO concentrations, and benthic community indices of total abundance and taxa richness (number of species or other taxanomic groups identified in a sample) at each of 30 stations are geographically displayed in Figure 2-11. Total abundance and taxa richness appear to be positively related to each other and to DO levels at these stations and to be inversely related to percent fines and TOC levels in the sediments.

Examination of the geographic distribution of the abundance of the species and the dominant taxa at each station, suggests different suites of animals in five different regions of Hood Canal (Figure 2-12). Benthic assemblages in stations in northern Hood Canal are composed primarily of a mixture of annelids, arthropods, and molluscs. Dominant species include *Macoma carlottensis* and *Axinopsida serricata* (both widespread bivalves throughout Hood Canal) and a stress-sensitive ostracod (*Euphilomedes* spp.). In the central region of the canal, the shallow-nearshore station assemblages are primarily a mix of annelids and molluscs, but have fewer arthropods. Assemblages in the deepwater central channel of the central region of the canal are composed primarily of chaetopterid annelids. Assemblages in Dabob Bay and the southern part of the canal are composed mainly of differing suites of stress-tolerant annelids and molluscs, while stress-sensitive arthropods are absent. Dominant stress-tolerant annelids in Dabob Bay included a number of species of capitellids, *Cossura bansei, Lumbrineris cruzensis,* and *Leitoscoloplos pugettensis*. The bivalve *M. carlottensis* was again dominant. In southern Hood Canal, the bivalve *A. serricata* was dominant, along with a number of stress-tolerant cirratulid, capitellid, and pectinarid annelids.

Benthic infaunal indices were pooled within five ranges of near-bottom water DO concentrations for analysis (Figure 2-13). In general, indices decreased as DO levels decreased. Abundance patterns were also examined for 17 species thought to have differing sensitivities to DO levels. Some species increase in number with slightly lower DO, but most responded negatively to DO levels lower than 3 mg/l. (Figure 2-14, page 36).

Re-establishing Olympia Oysters in Puget Sound

Washington's only native oyster, the Olympia oyster (*Ostreola conchaphila*), has been the focus of cooperative research and restoration efforts in recent years. Olympia oysters commonly occur throughout Hood Canal and southern Puget Sound, wherever suitable intertidal habitat is available. Loss or lack of shell substrate appears to be a limiting factor in several areas where native oysters were historically present in large numbers. Restoration efforts in Liberty Bay provide this missing substrate by adding Pacific oyster shell to soft, muddy areas. A similar restoration project using Pacific oyster shell is underway in Discovery Bay, where European explorers to the Northwest first encountered Olympia oysters.

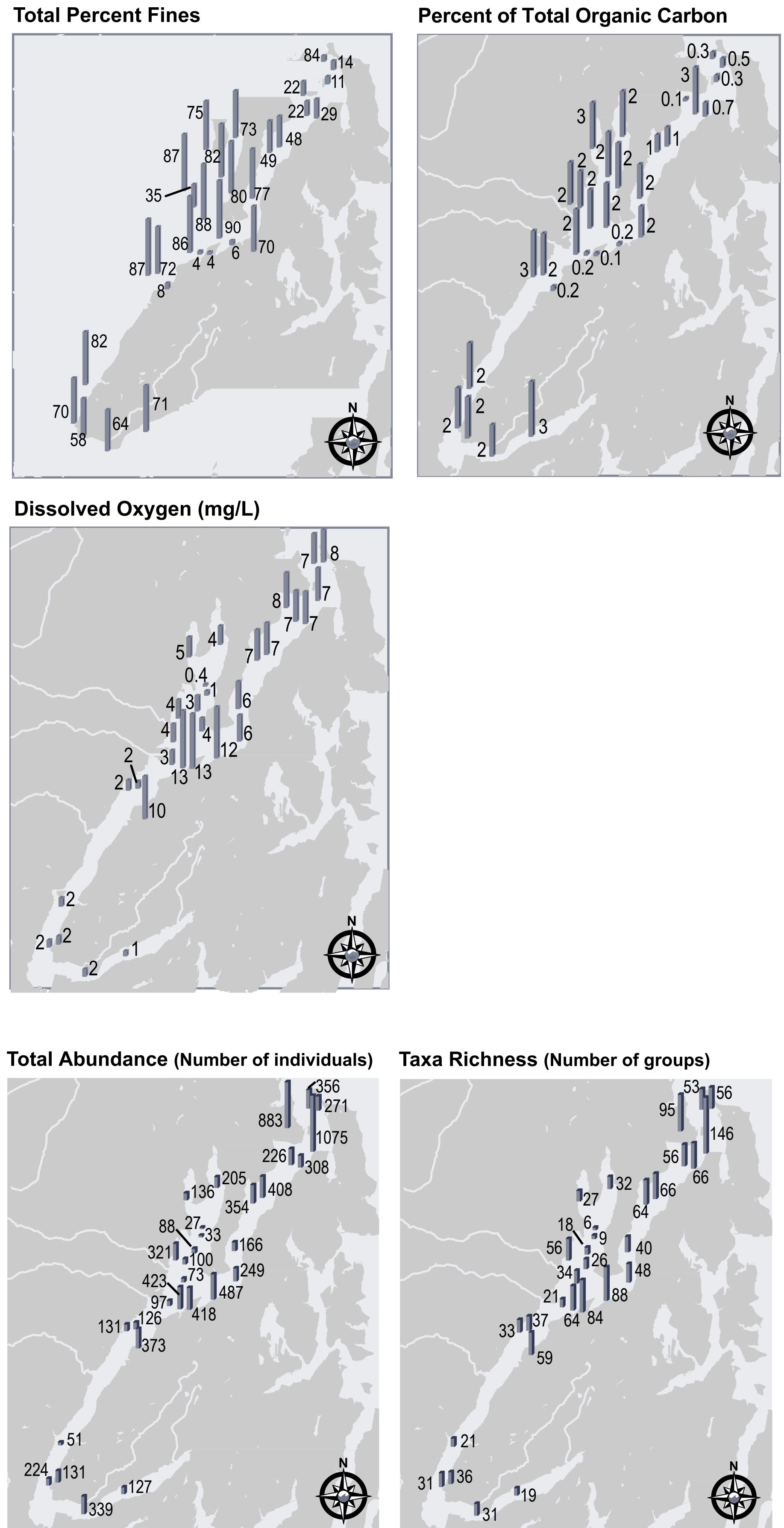


Figure 2-11. Taxa richness in Hood Canal. Sediment grain size, total organic carbon, near-bottom dissolved oxygen, benthic infauna and taxa richness measured at 30 Hood Canal stations in June 2004. Abundance and taxa richness appear to be positively correlated to DO levels and negatively to grain size and TOC.
(Source: Ecology)

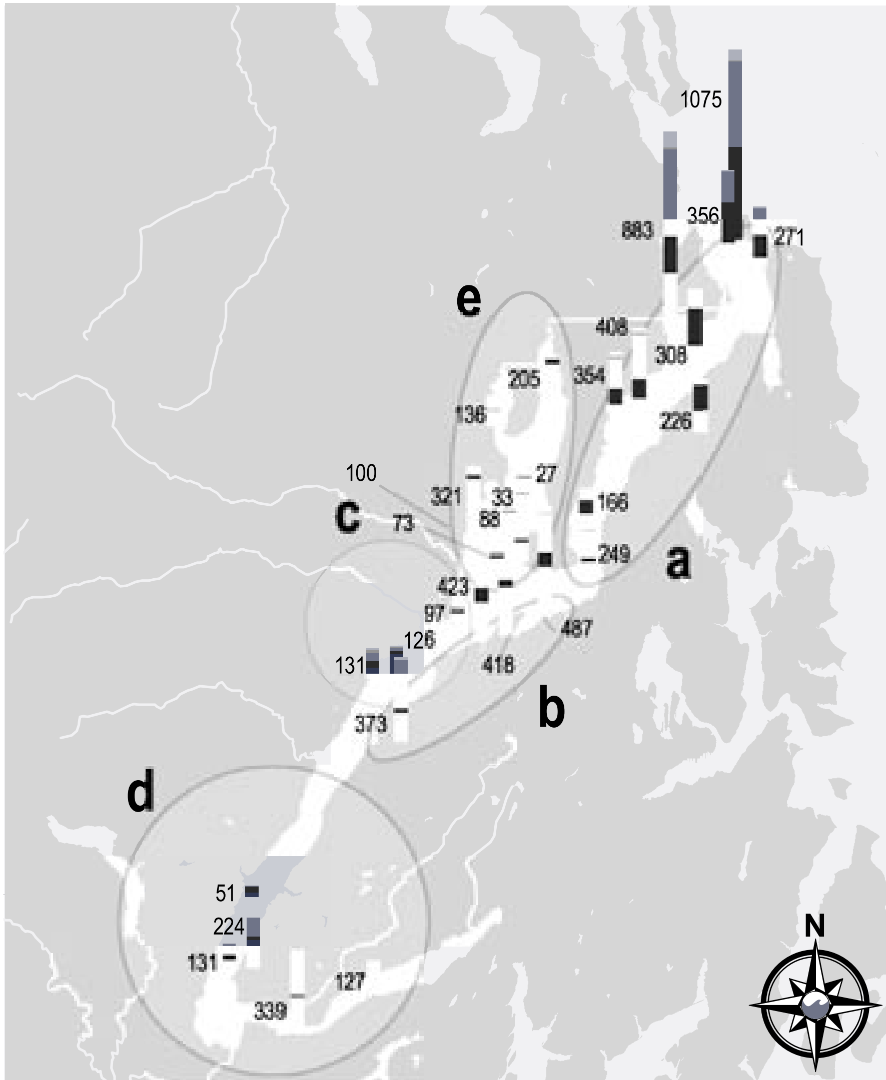


Figure 2-12. Major taxa abundance in Hood Canal. Abundance of major infaunal invertebrate groups measured at 30 Hood Canal stations in June 2004. Five groups of stations with similar assemblages were identified: northern (a), central near-shore (b), central deep (c), and southern (d) Hood Canal and Dabob Bay (e) (Source: Ecology)

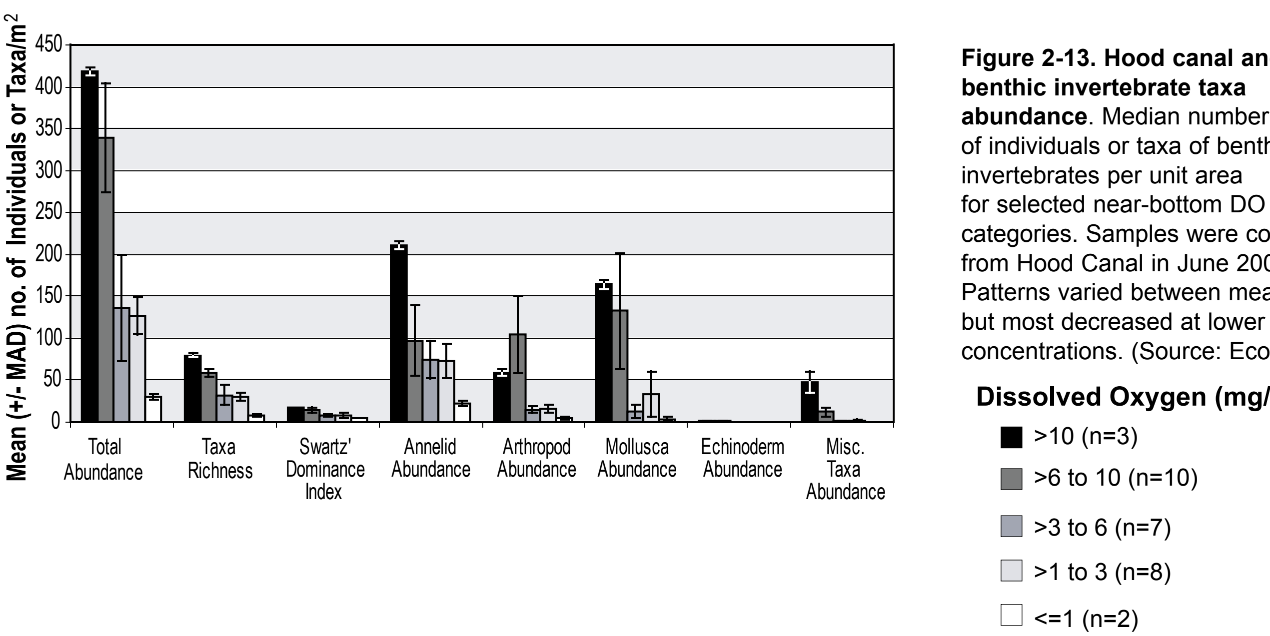
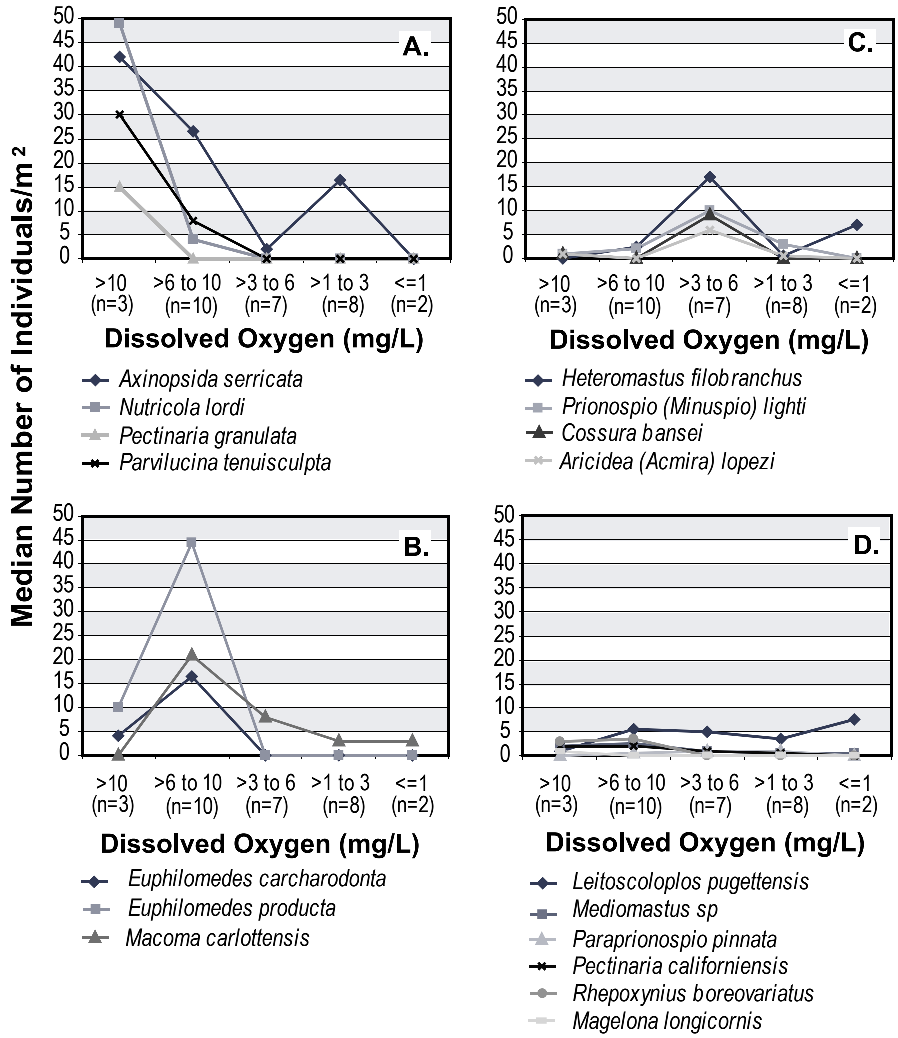


Figure 2-13. Hood canal and benthic invertebrate taxa abundance. Median number of individuals or taxa of benthic invertebrates per unit area for selected near-bottom DO categories. Samples were collected from Hood Canal in June 2004. Patterns varied between measures, but most decreased at lower DO concentrations. (Source: Ecology)

Figure 2-14. Impact of low dissolved oxygen (DO) on Hood Canal's invertebrates. The relationship between species abundance and near-bottom DO levels at 20 Hood Canal stations sampled in June 2004. The abundance of most species drops dramatically at low DO concentrations. (Source: Ecology)



Impacts to the Ecosystem

The pattern in losses of valued benthic organisms measured in Hood Canal in 2004 resembles that described previously for other fjords (Pearson and Rosenberg 1976). The most sensitive species found were among those previously identified elsewhere as most at-risk from the effects of hypoxia (Diaz and Rosenberg 1995). However, because many other natural factors can influence the structure of infaunal invertebrate communities, the actual causes of benthic impairment in Hood Canal are not certain. It is probable that the DO concentrations are limiting and contributory, but they may not be the sole cause of impairment. Results of this study will serve to better quantify the relationships between sediment and water column variables that impact benthic invertebrate communities in Hood Canal and will improve our ability to predict the impact of continued decreasing DO levels on these communities and the populations of bottom-feeding fish and macroinvertebrates that rely on benthic invertebrates as food sources.

Human Health Consequences

Low dissolved oxygen in marine waters does not directly affect humans, but several major fish kills that may be associated with hypoxia have occurred in Hood Canal during the past several years. The results of the 2004 sediment quality survey also suggest that Hood Canal's infauna is adversely affected by hypoxia. Many of these species are important prey for fish, such as sole and flounder, and invertebrates, such as shrimp and crabs, that support valuable commercial and recreational fisheries.

b. Geoduck Clam

The large burrowing Pacific clam (*Panopea abrupta*), also known as the geoduck, is abundant and an important suspension-feeder in the inland waters of Puget Sound. The geoduck is long-lived (162+ years), and represents a large portion of the animal biomass embedded in the benthos. Geoducks have historic cultural significance to tribal communities and have been harvested in the intertidal zone by Washington residents since the late 1800s. The subtidal geoduck population has been commercially exploited since 1969, with harvest occurring in south and central Puget Sound, Admiralty Inlet, northern Hood Canal, and the eastern Strait of Juan de Fuca. Geoduck beds are found outside of these regions but may encompass smaller areas and have lower average densities than commercial beds.

Status and Trends

The statewide geoduck biomass estimate from commercial beds was 181 million pounds in 2005. The stock assessment information for geoduck populations is gathered through scuba surveys between the water depths of -18 to -70 feet (-5 to 121m)[5]. An additional 47 million pounds are estimated but were unavailable for commercial harvest, because of pollution status. The geoduck fishery continues to be the largest and most economically important clam fishery on the west coast of North America. In 2005, the combined state and tribal commercial geoduck harvest was 4.6 million pounds (Figure 2-15).

Estimates of geoduck biomass have increased over time (Figure 2-16), because of increased survey and harvest area and refinement and reduction of closed and prohibited area classifications by the Washington Department of Health. In 1996, the statewide commercial geoduck biomass estimate was about 134 million pounds and, in 2005, this estimate had increased to 181 million pounds.

Despite the recent increase in harvestable biomass, geoduck recruitment (establishment of new individuals) appeared to be in decline from the 1920s to the 1980s, in both British Columbia and Washington state. A focused effort to obtain large samples of geoduck (500 to 1,000 animals per sample site) from many locations was undertaken from 1999 to 2005, to age the individuals and examine trends in spatial and temporal patterns of geoduck recruitment. Although analysis is continuing, the work has helped to confirm a relative decline in geoduck recruitment from the mid-1950s through the mid-1970s and more recently an improvement in recruitment. It is believed that recruitment has returned to historic levels; however, the environmental factors that may have contributed to the observed trends are under further study. Preliminary results indicate that the geoduck population is healthy and the commercial fishery is being managed on a sustainable basis.

Impacts to the Ecosystem

Along with oysters, mussels, and other clam species, geoducks are important grazers of phytoplankton in Puget Sound. Examination of geoduck gut contents suggests that geoducks feed exclusively on phytoplankton. Removal of geoducks might affect phytoplankton levels on a localized basis, although geoducks in the upper photic zone are not harvested in the commercial clam fishery.

[5] Corrected to the 0.0-foot tide level.

Figure 2-15. Landings and values of commercial geoduck clams fisheries in Washington. Landings are the same as harvests in commercial fisheries whereas biomass is calculated from surveys. (Source: WDFW)

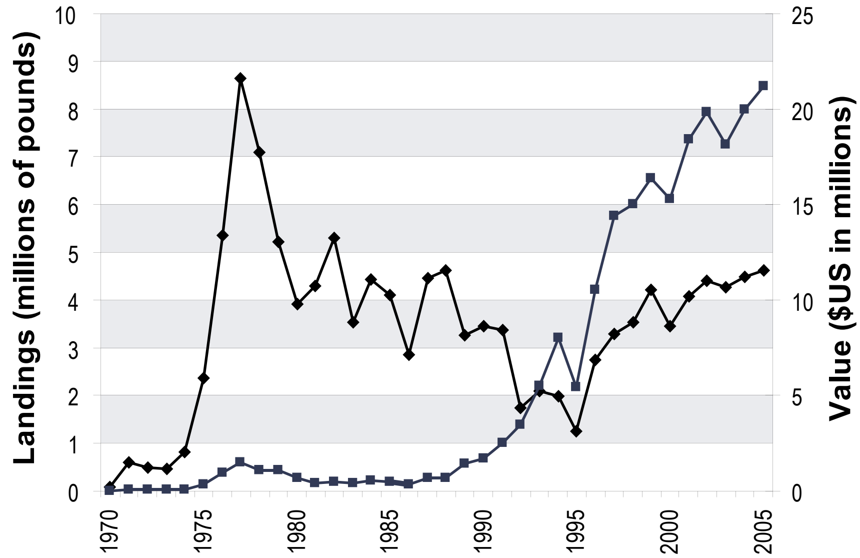
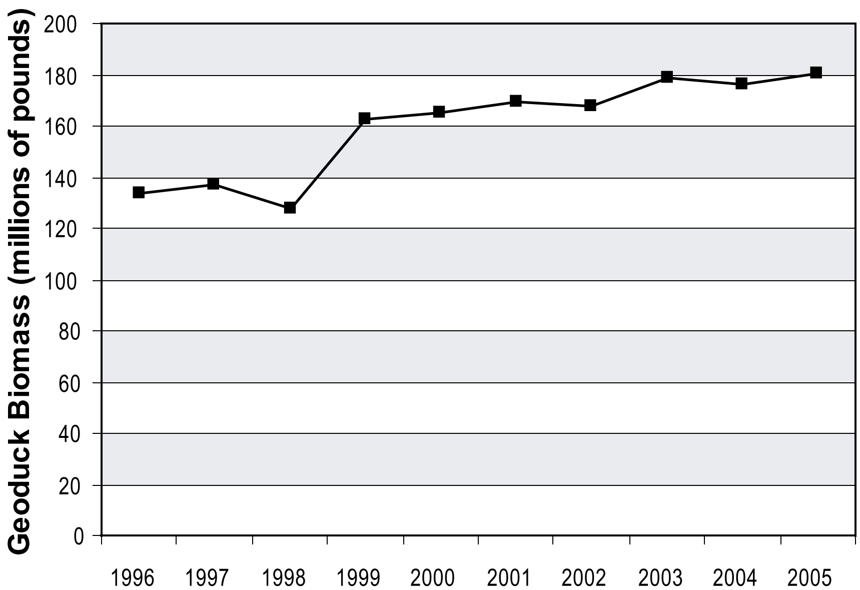


Figure 2-16. Geoduck biomass estimates for Puget Sound. Changes in commercial geoduck biomass estimates over the last 10 years, based on scuba surveys. Surveyed biomass estimates have increased during this period. (Source: WDFW)



Focus Study

Geoduck Studies in Hood Canal

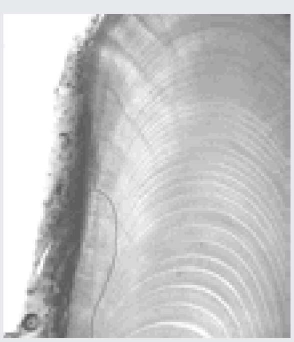


Figure 2-17. Cross-section of geoduck shell, showing annual growth rings. Photo courtesy of Juan Valero, University of Washington

Stock assessment surveys of subtidal geoduck populations in Hood Canal have been ongoing since 1969. Most of these surveys have been conducted using scuba transects between the -18 ft and -70 ft (-5 to 21m) water depths. In 2005, the Washington State Legislature required DNR to conduct a two-year study to determine if geoduck populations in Hood Canal have changed over time and, specifically, if they have been affected by recent low DO events. Geoduck shell chemistry may be used to reconstruct environmental conditions that may have been experienced by geoducks over the past several decades.

The initial phase of the Hood Canal study examined geoduck density changes on unharvested "tracts" in southern, central, and northern Hood Canal. Density estimates were then compared with prior surveys dating back to 1974. The second phase of this study includes studying geoduck shells from large samples (600+ animals from each subregion) to obtain age/frequency distributions and to analyze spatial and temporal geoduck recruitment patterns.

Human Health Consequences

Filter feeders remove substances from the water column and may help in removal of pathogens and toxics from the environment. The potential of geoduck clams to consume and bioaccumulate hazardous substances in the marine environment is not well studied; however, Ecology does have an ongoing evaluation program to assess levels of PSP toxins in geoduck tissue from commercial tracts. The high value of the geoduck clam resource has made the geoduck a prime target for illegal harvest, which could include harvests from polluted areas. If polluted clams, taken illegally, should make it into the marketplace, then there is a risk of human injury or death, as well as possible damage to the commercial clam fishery and the livelihoods of those involved in the fishery.

c. Sea Urchin

Three species of sea urchin—red, green, and purple—occur commonly within the inland marine waters of Washington state. Of these, red (*Stronglyocentrotus franciscanus)* and green (*Stronglyocentrotus droebachiensis*) sea urchins support important tribal and state commercial fisheries. Based on observed trends in fishery-dependent data (primarily on catch per unit effort) and direct stock assessment (abundance and size frequency), the Puget Sound sea urchin population is generally considered stable. However, population declines in specific geographic areas have necessitated harvest reductions or complete area closures because of stock conservation concerns.

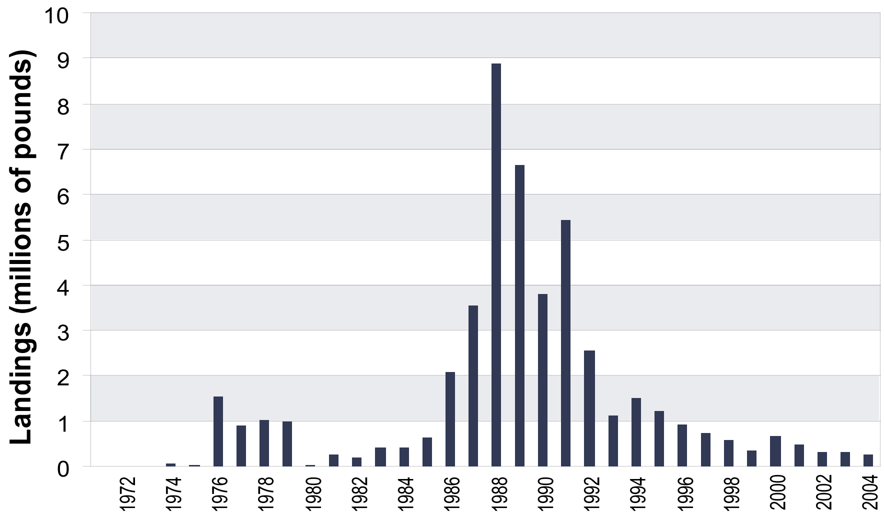
Status and Trends

The Washington state commercial fishery for red sea urchin began in 1971. The average annual landing total for the period between 1976 and 1986 was 279 metric tons (Figure 2-18). During the late 1980s, an increase in price caused a rapid expansion of harvest activities, and the red sea urchin catch rates rose sharply during this period, peaking during the 1988-1989 season. Since the early 1990s, and in response to documented declines in red sea urchin populations, annual harvest quotas have incrementally limited red sea urchin catches. Current red urchin harvest levels are 83 percent less than those from the early 1990s and 97 percent less than the peak season of 1988-1989. For the 2004-2005 harvest season, 114 metric tons of red sea urchin were landed.

The age of geoducks can be determined by analyzing the growth patterns in annuli (annual growth increments), which are analogous to growth rings in trees (Figure 2-17). This information can also be used to construct catch curves and estimates of instantaneous natural mortality for each subregion in Hood Canal. Another part of the second phase is to establish index stations for geoducks, to determine relative changes in abundance from recruitment, growth, and natural mortality.

A third phase of the Hood Canal study is to sample annuli in shells from geoducks dug in the second phase, to determine patterns of change in shell chemistry over time. This study will look for links between geoduck growth patterns with climatic conditions, including seawater temperatures and influx of fresh water from river discharges. Ratios of stable isotopes in geoduck shells and the relative oxidation states of elemental iron and magnesium in the shell matrices may also provide a pattern of oxygen-rich and oxygen-poor conditions experienced by geoducks. The geoduck is a good candidate for this type of analysis, because it is long-lived, and sufficient samples can be obtained to cross-validate growth patterns.

Figure 2-18. Landings of red sea urchins in Washington from 1971-2004. During the late 1980s, an increase in price caused a rapid expansion of the harvest, and red sea urchin catch rates rose sharply, peaking during the 1988 - 1989 period. Co-management of sea urchins between Washington State and tribes began in 1994 and resulted in annual harvest quotas to address the documented declines in red sea urchin populations. (Source: WDFW)



In 2004, a stock assessment survey of red urchins in the eastern Strait of Juan de Fuca determined that the harvestable (legal-sized) biomass was approximately 60 percent lower than that established by a survey completed in 2001 and approximately 84 percent lower than an estimate of biomass in 1991. Based on this significant and continued declining trend, sea urchin co-managers decided that a commercial harvest closure was necessary to avoid a collapse of the fishery stocks and to evaluate population dynamics in the absence of harvest.

Green sea urchin commercial fisheries in Puget Sound began in 1986. Green sea urchin landings peaked in 1988, when 461 metric tons were landed (Figure 2-19). Since 1995, landings have remained relatively stable, averaging about 100 metric tons per year. For the 2004-2005 harvest season, 87 metric tons of green sea urchin were landed statewide.

Predation from an expanding Washington state sea otter population has also resulted in significant reduction of sea urchin abundance in some localized populations in the western Strait of Juan de Fuca. A 1995 survey of red sea urchins in the Neah Bay harvest management area indicated a 71 percent reduction in population levels from a survey completed the previous year. This reduction was directly attributed to sea otter foraging during a documented range expansion of approximately 120 sea otters wintering in the Neah Bay area. Since this initial sea otter incursion, two additional documented sea otter range extensions have occurred (in 1998 and 2000) within the Strait of Juan de Fuca. A 2003 urchin survey within the Sekiu harvest management area indicated significantly reduced red sea urchin populations in localized areas. These areas corresponded to areas of documented sea otter occupation during range expansions.

Impacts to the Ecosystem

Sea urchins have been identified as the primary herbivores of Puget Sound's marine macroalgae. The ecological relationships between sea urchins and marine algal communities have been well documented. Sea urchins can be highly effective grazers of brown algae, specifically those species, such as *Nereocystis* sp. and *Macrocystis* sp., that make up kelp forests. In high enough densities and in the absence of predators, sea urchin populations can create barrens (areas denuded of macroalgae). Puget Sound ecosystem linkages to this urchin/kelp relationship may include species highly dependent on kelp assemblages (such as marine fish) or species found in association with urchin barrens (such as pinto abalone). While the dynamics of sea urchin grazing on macroalgae are quite evident, these secondary species relationships are not well understood.

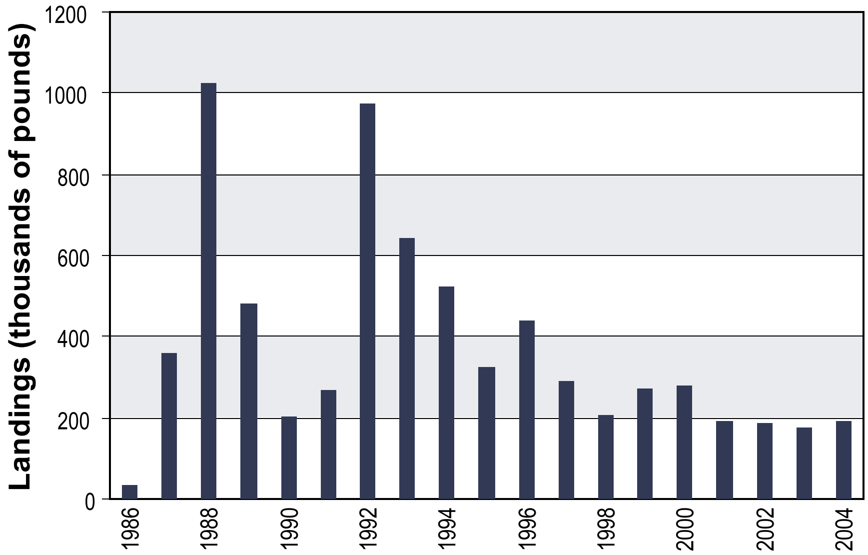


Figure 2-19. Landings of green urchin in Washington from 1986 - 2004. As with the red urchin, an expansion of green urchin harvest occurred during the mid-1980s. Green urchin landings have been relatively stable, following the onset of more controlled harvest practices in the early 1990s. (Source: WDFW)

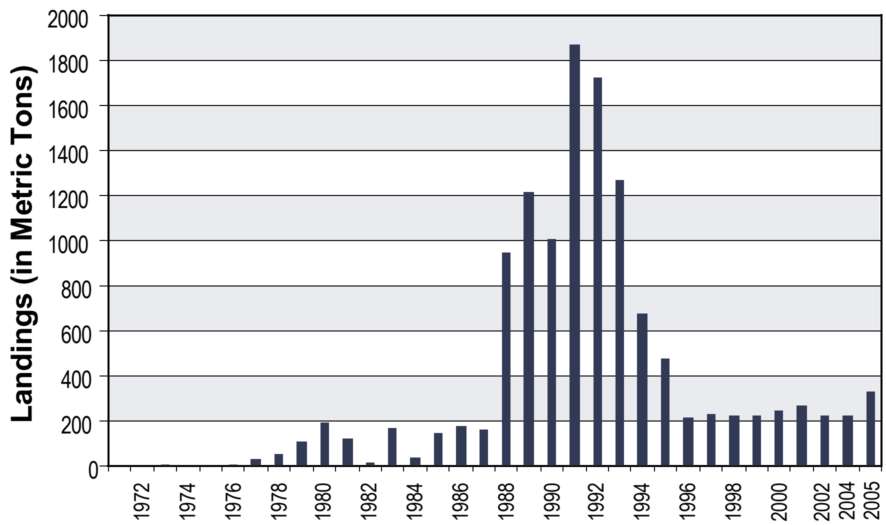


Figure 2-20. Sea cucumber landings in Washington, 1971 - 2005. Commercial harvest began in the early 1970s and, in 1994, sea cucumber harvest quotas were established for all management areas. Annual harvest quota amounts have remained fairly stable since that time. (Source: WDFW)

d. Sea Cucumber

The red sea cucumber (*Parastichopus californicus*) is ubiquitous throughout Puget Sound. It occupies a wide range of habitats, from soft mud bottoms of quiet embayments to current-swept rocky substrates and can be found from the shallow intertidal to at least 650 ft (223 m). Little is known about the basic biology and trends in abundance of the red sea cucumber in Puget Sound even though populations support a significant tribal and non-Indian commercial fishery.

Status and Trends

Commercial sea cucumber harvest began in 1971 and, since then, fishery-dependent data and limited survey information have been used to monitor and regulate sea cucumber harvests. Initially, sea cucumber harvest was permitted as an experimental fishery. Landings were relatively low and variable, averaging 188.7 metric tons between 1978 and 1987 (Figure 2-20). Harvest effort in the fishery increased dramatically, beginning in 1988 and peaking in 1991 at an annual harvest of 1,865.4 mt. The rapid increase in harvest activity led to more intensive management efforts. The current harvest management scheme is considered conservative, relative to historic high rates; however, the real harvest impact remains uncertain due to a lack of biological information.

Impacts to the Ecosystem

Throughout the world, sea cucumbers have been identified as serving an important marine ecological niche in the processing of benthic detrital materials. They may also serve as integral components in marine biogeochemical cycling. Algal blooms in Puget Sound may inhibit eutrophication because nutrients are removed from the water column. However, as the algae dies and settles to the bottom, it may cause anaerobic conditions immediately above and on the sediment layer. The role of the red sea cucumber in Puget Sound is not well understood; however, other deposit-feeding holothurians have been linked to inhibiting this anaerobic process. In laboratory experiments, algal biomass and organic matter concentrations on the substrate are reduced when deposit-feeders are present. Declining sea cucumber populations worldwide have been an issue of recent debate. Sea cucumbers are extremely vulnerable to over-exploitation due to their late maturity, density-dependent reproduction, low survival of larvae, and ease of collection by humans. Many sea cucumber fisheries around the world are over-exploited. These declining populations not only result in a reduction of harvestable product but may have a prolonged impact on sediment cycling.

e. Pinto Abalone

Pinto abalone (*Haliotis kamtschatkana*) are most commonly found in nearshore rocky habitats at depths ranging from shallow subtidal to 35 ft (10.7 m). Individuals are occasionally found at deeper depths, over 100 ft (30.5 m). Adults feed on drift macroalgae, with the major component of the diet being giant kelp. Abalone have a relatively short planktonic larval phase, which lasts between four to seven days. A specific type of algae called crustose coralline algae may play an important role in the settlement of larval abalone onto suitable rocky habitat. Abalone may also be associated with red and green sea urchins. These three animals are important herbivores in the nearshore rocky environment and keep rocky substrate clear, allowing settlement of other invertebrate species.

Status and Trends

Data from 10 index sites in the San Juan Archipelago from 1992 to 2005 and anecdotal information from historic abalone observations suggest the pinto abalone is undergoing significant declines. Commercial harvest of abalone has never been permitted, and statewide recreational harvest of abalone was closed in 1994. WDFW listed the pinto abalone as a candidate species for protection in 1996, and NOAA Fisheries listed it as a species of concern in 2004.

Focus Study

Sea Cucumber Recruitment Study

In 2005, WDFW initiated a fishery independent pilot study to test the feasibility of using juvenile sea cucumber collecting devices as an index to determine sea cucumber recruitment. At each of three locations throughout Puget Sound, 12 juvenile sea cucumber collectors were installed and monitored. Juvenile sea cucumbers were found in collectors at two of the three study sites. Initial settlement was by juvenile sea cucumbers ranging in size from 0.12 inches (3 mm) to 0.67 inches (17 mm). Future implementation of monitoring systems to study long-term annual recruitment could provide managers with an important population assessment tool for detecting trends in the health of exploited sea cucumber populations. Given the wide range of habitat types and depths that sea cucumbers inhabit, monitoring juvenile red sea cucumber recruitment in Puget Sound could serve as a useful indicator of overall ecosystem health.

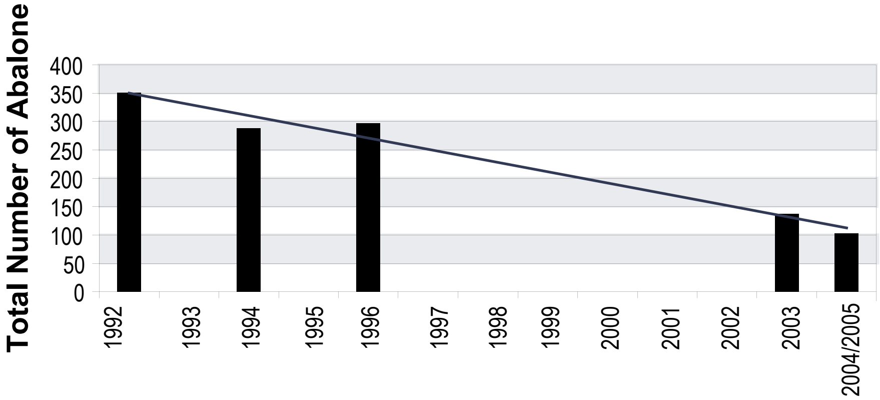


Figure 2-21. Abalone abundance in San Juan Archipelago. Abalone abundance at 10 index stations from 1992-2005 in the San Juan Archipelago indicates a steady decline in number of animals per site. Even with the elimination of fishing in 1994, pinto abalone continue to decline dramatically throughout Washington. (Source: WDFW)

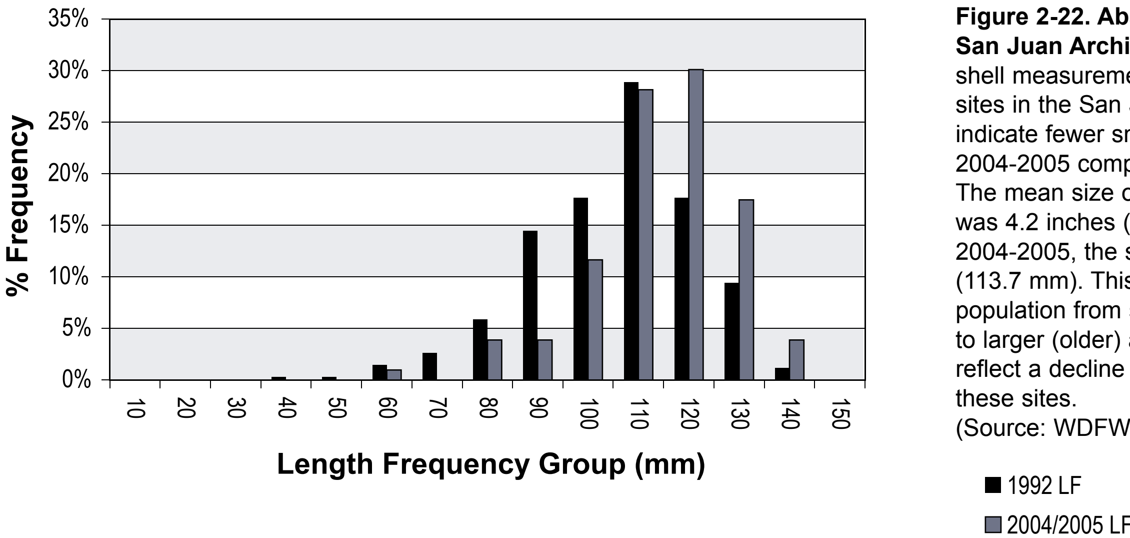


Figure 2-22. Abalone shell size in San Juan Archipelago. Abalone shell measurements from index sites in the San Juan Archipelago indicate fewer smaller animals in 2004-2005 compared with 1992. The mean size of abalone in 1992 was 4.2 inches (105.3mm), and, in 2004-2005, the size was 4.5 inches (113.7 mm). This suggests a shift in population from smaller (younger) to larger (older) animals, which may reflect a decline in recruitment at these sites. (Source: WDFW)

Between 1979 and 1980, WDFW conducted dive surveys at 30 locations in the San Juan Archipelago. Twenty-three of these stations were re-visited between 1990 and 1991. Comparisons showed that abalone numbers had declined by roughly 50 percent from 1979 to 1991. Counts at one site had increased, counts at four of the sites were the same, nine sites had fewer abalone, and no live abalone could be found at the remaining nine sites.

Because of problems with duplicating the original survey method, WDFW established 10 permanently delineated abalone index sites in 1992. These sites were distributed around the perimeter of the San Juan Archipelago. The sites range in size from 1,453 ft^2 (135 m^2) to 4,090.3 ft^2 (380 m^2), and individual animals are counted during each survey. The site surveys have been repeated in 1994, 1996, 2003, and 2004-2005. Data from these surveys show a trend of continued decline in abalone abundance of roughly 70 percent from 1992 to 2004-2005 (Figure 2-21). Limited data exist for the Strait of Juan de Fuca populations, but anecdotal information suggests similar trends to those observed in the San Juan Archipelago.

WDFW also conducted shell length surveys to measure abalone age demographics from the index sites. Shell length data show a significant decrease in smaller abalone (less than 35.4 inches or 90 mm in shell length) since 1992. The mean length of abalone at index sites in 1992 was 4.2 inches (105.3 mm). By 2004-2005, the mean had increased 0.3 inches (8.4 mm) to 4.5 inches (113.7 mm) in length (Figure 2-22), representing a shift in the population from smaller (younger) to larger (older) animals.

It appears from the San Juan data that abalone in Washington state are experiencing recruitment failure. This failure is not completely understood. It may represent an Allee effect, in which reproductive potential of the population is reduced through shift in age distribution of individuals and decline in the density of organisms. Abalone and other broadcast-spawning sedentary invertebrates need minimum densities of >1.1 to 0.5 individuals per ft^2 (>0.33 to 0.15 individuals per m^2) for successful reproduction (Babcock and Keasing 1999). In 1996, five of 10 stations fell within this density threshold. By 2003, only one of 10 stations was within this range. Other research has shown that juvenile abalone recruitment drops significantly, or is eliminated entirely, if the adult population drops below 50 percent of its initial density (Richards and Davis 1993). WDFW data suggest that similar magnitudes of decline have occurred at least twice over the past 25 years.

Impacts to the Ecosystem

Abalone are important herbivores in nearshore rocky habitats. In conjunction with other herbivores, such as red, green, and purple sea urchins, they have the ability to bio-engineer—that is, change—their local ecosystems. These important herbivores keep areas of rocky habitat open for settlement by other marine invertebrates. While the primary consequence of large populations of herbivores grazing on macroalgae is quite evident in the form of urchin barrens (areas where urchins have extensively grazed algae down to bare rock), the secondary consequence of species diversity and composition is not well understood.

f. Puget Sound Crabs

Several species of crab are found in Washington's marine waters and along its shores. Dungeness crab (*Cancer magister*) is the primary target for commercial and recreational fishers with some non-commercial effort focused on red rock and graceful crab. Puget Sound's Dungeness crab fisheries target males only, with a minimum shell carapace width of 6.25 inches (158.8 mm). The seasons of the fisheries occur only when 80 percent or more of the legal-sized males are in hard shell condition, in order to reduce fishing-induced mortality on the grounds. The design of Puget Sound's Dungeness crab fisheries begins with the conservation criteria and includes allocation objectives required to meet state and federal mandates.

Status and Trends

Currently, there is no monitoring of crab populations and harvest numbers are used to reflect abundance and, thus, estimate the population size. Three criteria—sex, size, and season—are factored into the population estimates. Dungeness crab harvest trends since the 1995-1996 season show a stable and steady increase from six million pounds per season to eight million pounds per season taken from Puget Sound by all groups (Figure 2-23).

7. Fish

a. Groundfish

Groundfish are those marine fish species that live near or on the bottom for most of their adult lives. Over 150 groundfish species inhabit Puget Sound, and several of these once supported thriving commercial and recreational fisheries. Groundfish species also comprise a major component of the biomass of the Puget Sound ecosystem and contain many links in the food web, connecting nearshore and midwater components to the benthos. During the past two decades, species including Pacific cod (*Gadus macrocephalus*) and Pacific hake (*Merluccius productus*),

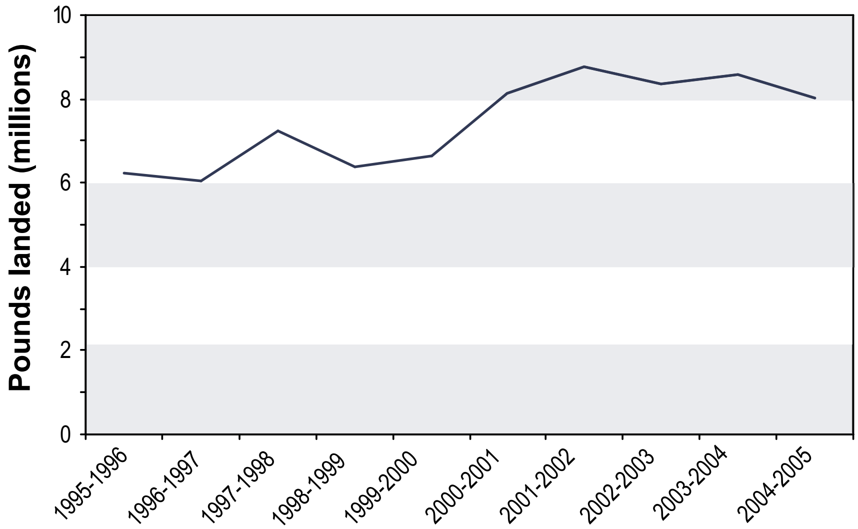


Figure 2-23. Puget Sound Dungeness crab harvest. Current estimates of crab abundance are based on pounds harvested. The sex, size, and season of the catch help determine the remaining crab abundance. Between 1995 and 2005, the biomass of crab harvested annually has increased from six million pounds (2.7 million kilograms) to approximately eight million pounds (3.6 million kilograms).
(Source: WDFW)

walleye Pollock (*Theragra chalcogramma*), spiny dogfish (*Squalus acanthias*), and several species of rockfish have declined to alarmingly low levels. Among the species in decline are many major predators of fish and shrimp that linked lower trophic levels with upper ones. In 1999, petitions for most of these species were filed to NOAA Fisheries for consideration under the ESA. The subsequent review did not find sufficient evidence of genetic uniqueness or of decline that threatened extinction; however, Pacific hake remained a federal candidate species. In addition, cod, pollock, hake, and 13 species of rockfish were added as candidate species to the Washington State Endangered Species List. In mid-2006, a new ESA petition was filed to consider copper (*Sebastes caurinus*) and quillback (*Sebastes maliger*) rockfish in waters south of Port Townsend as threatened or endangered.

WDFW co-manages groundfish with the treaty tribes of Washington. WDFW has reviewed the status of many groundfish species (Palsson et al. 1997, PSAT 2000, PSAT 2002) and found that the majority of stocks have been in poor condition in north and south Puget Sound. WDFW's management approach is defined under the Puget Sound Groundfish Management Plan (Palsson et al. 1998), which outlines a precautionary approach to management through the creation of conservation and harvest plans. The management of most groundfishes is separated into two regions: North Sound (the Strait of Juan de Fuca, San Juan Archipelago, and the Strait of Georgia and adjacent bays) and South Sound (Puget Sound proper, Hood Canal, the Whidbey Basin, and Southern Puget Sound).

Status and Trends

Previous reviews of groundfish populations in Puget Sound have primarily depended upon the relative measures of how well fisheries have performed over time. With the decline of important groundfish populations and the corresponding restrictions of their fisheries, most of these fishery-dependent measures are no longer as useful. WDFW has been conducting surveys that do not depend upon the performance of commercial and recreational fisheries and that also mirror the relative change in fish populations without having to control for changes in fisheries management actions. The primary survey has been the bottom trawl survey, conducted at irregular intervals since 1987 (Schmitt and Quinnell 1989, Palsson et al. 2002, 2003), and the trend results of this and scuba and video surveys generally correspond to the trends in fishing performance (Palsson 2002).

Table 2-3. 2006 Groundfish stocks status in Puget Sound. North Sound is defined as the Straits of Juan de Fuca and Georgia and the San Juans; South Sound is defined as those waters south of Port Townsend. While the trend categories of above average, average, below average, depressed, and critically depressed do not necessarily represent biological reference points, they roughly correspond to limits established by fishery managers for maintaining healthy spawning biomasses or the criteria for marine fish stocks at risk. (Source: WDFW)

Species	North Sound	South Sound
Spiny Dogfish	Below average	Depressed
Skates	Below average	Above Average
Spotted Ratfish	Average	Above Average
Pacific Cod	Critical	Critical
Walleye Pollock	Below Average	Critical
Pacific Whiting	Above Average	Critical
Rockfishes	Critical	Critical
Lingcod	Above Average	Above Average
Sablefish	Critical	Average
Greenlings	Unknown	Average
Wolf-eel	Unknown	Unknown
Surfperches	Unknown	Below Average
Sculpins	Above Average	Above Average
English Sole	Above Average	Above Average
Rock Sole	Above Average	Below Average
Starry Flounder	Above Average	Average
Dover Sole	Average	Depressed
Sand Sole	Average	Above Average
Pacific Halibut	Above Average	Above Average
Other Groundfish	Unknown	Unknown
Good Condition	12	9
Poor Condition	6	9
Unknown	2	2

For the purposes of this report, survey or fishery trends will be reviewed and compared to the criteria established by Palsson et al. (1997). While the trend categories of above average, average, below average, depressed, and critically depressed do not necessarily represent biological reference points, they roughly correspond to limits established by fishery managers for maintaining healthy spawning biomasses or to the criteria for marine fish stocks at risk (Musick 1999). When applying trawl survey trends in north Puget Sound to stock assessment, only the results from the southern Strait of Georgia and eastern Strait of Juan de Fuca will be used to characterize the entire area.

As of 2005, almost 60 percent of the groundfish stocks in Puget Sound were in good (average or above-average) condition (Table 2-3)—a change over the previously evaluated stock conditions that were either equivocal or mostly in poor condition. In the North Sound, 10 stocks were in good condition, six were in poor condition, and the status of four stocks was unknown. In the South Sound, 10 stocks were in good condition, eight were in poor condition, and two were in unknown condition. In general, populations of codfishes continue to be in poor or critical condition, except Pacific hake in the North Sound. Most flatfish, sculpin, and lingcod populations are in above-average condition, dogfish populations are in poor condition, and rockfish populations are in critical condition.

Among the assessed sharks and skates, trawl survey of spiny dogfish biomass indicate that these populations have declined by 30 percent in North Sound and by 69 percent in South Sound resulting in status classifications of below average and depressed respectively. Skates were below average condition in North Sound, having declined by 32 percent among trawl surveys but were in above average condition in South Sound. Spotted ratfish, the most dominant species of groundfish, was in average condition in North Sound but has increased in biomass by 57 percent in recent times in South Sound, compared to the long-term average.

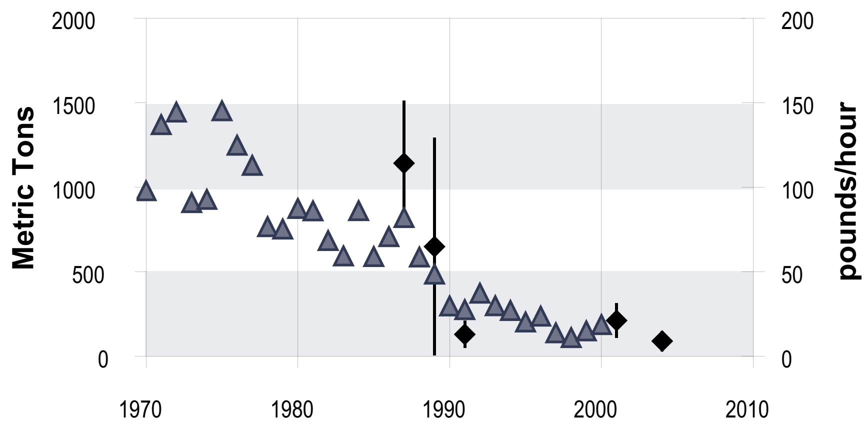


Figure 2-24. Pacific cod biomass in north Sound. Fishery and survey trends of Pacific cod abundance in the north Sound indicating a steady decline in this species since the mid-1970s. (Source: WDFW)

◆ Survey
▲ Trawl pounds/hour

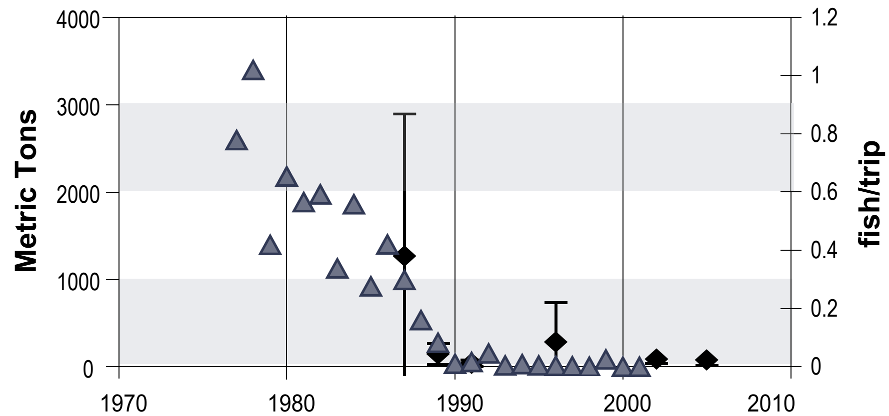


Figure 2-25. Pacific hake biomass in south Sound. Fishery and survey trends of Pacific cod abundance in the south Sound reveal a nearly depleted stock in the past 15 years. (Source: WDFW)

◆ Trawl
▲ Catch per unit effort

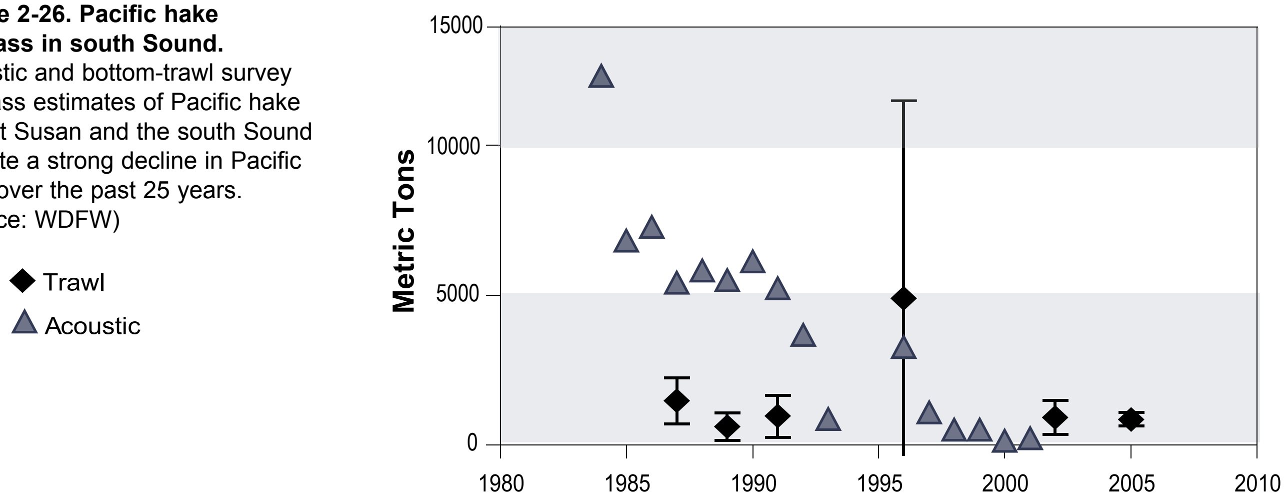
Most populations of codfishes, especially Pacific cod, have undergone dramatic declines in previous decades and have shown little signs of recovery despite prohibitions or restrictions on their fisheries. Pacific cod were once targeted by commercial and recreational fishers and were easily caught during the 1970s and early 1980s. However, indices of fishing success have declined by 60 percent before the commercial fishery in the Strait of Georgia and north Sound was restricted to quota management for cod in 1997 (Figure 2-24) and by 76 percent in the south Sound before the recreational fishery was closed in 1991 (Figure 2-25). The trawl surveys confirm that these trends are continuing. In North Puget Sound, recent biomass estimates have declined by 80 percent, and, in the south Sound, biomass estimates have declined by 75 percent compared to the 20-year mean status assessments of critical for both stocks.

Along with cod and pollock, Pacific hake (also known as Pacific whiting) was considered for ESA listing. In the north Sound, hake populations appear to be doing well, with recent trawl survey biomass 89 percent above the long-term mean (1980-2005). In the south Sound, hake in the Everett area were once assessed by an acoustic-trawl survey. Over time, the abundance of the adult population decreased by 78 percent, with some suggestion of a rebound in 2002, when the acoustic survey ended (Figure 2-26). The bottom trawl survey is not the best means to assess stocks of these pelagic fishes, but it does indicate a 47 percent decline over the long-term mean. As a result, the south Sound hake population status is characterized as critical.

What is a fish 'stock?'

A stock is an interbreeding group of fish that is reproductively isolated (spawning at a different location or time) from other such groups.

Figure 2-26. Pacific hake biomass in south Sound. Acoustic and bottom-trawl survey biomass estimates of Pacific hake in Port Susan and the south Sound indicate a strong decline in Pacific hake over the past 25 years. (Source: WDFW)



Recent biomass estimates of walleye pollock in north Sound were 32 percent below the long-term mean, resulting in a below-average status. In the south Sound, the recreational fishing success for pollock declined to zero by the late 1980s, but recent trawl survey biomasses are only slightly below the long-term average. The apparent recovery may be due to relatively abundant concentrations in the Port Townsend area. Regardless, the collapse of the pollock fishery and low abundance in more southern extremes results in a critical condition status for pollock in the south Sound.

Over 27 species of rockfishes have been recorded in the inland marine waters of Washington. Only 10 of these have been commonly captured in recreational fisheries and two, copper and quillback rockfishes, are the most dominant species. Fishery and survey data are most available for these two species. The fishery-dependent information is used to estimate the spawning potential index of these common species. This index combines the changes in size composition of the populations and the corresponding fecundity with and the index of relative abundance based upon the fishing success of the recreational anglers fishing success. From the mid-1970s to 1999 (the last year of relatively unrestricted fishing), the spawning potential curves declined to less than 26 percent of either copper or quillback rockfishes in the north or south Puget Sound (Figures 2-27 and 2-28). Trawl, scuba, and video surveys of rockfish corroborate these continued declining trends in most regions as exemplified by the declining abundance of quillback rockfishes in south Sound observed from trawl surveys (Figure 2-29) and result in critical classifications for rockfishes in both the north Sound and south Sound.

Many other populations of groundfish are thriving. In particular, English sole (*Parophrys vetulus*), most other flatfishes, and lingcod (*Ophiodon elongatus*) are in above-average condition in the north and the south Puget Sound. Lingcod in the north Sound were abundant during the late 1970s and early 1980s, but declined to extremely low abundance in the early 1990s (Figure 2-30). Changes to fishing regulations and the fish's good survival resulted in increased harvest success in recent years. In the south Sound, increasing success in lingcod fishing has occurred since the early 1980s when fishing was resumed after a five-year moratorium.

All monitored flatfish species are in average or above-average abundance in the north Sound, with recent English sole biomass 42 percent greater than the long-term average. After several years of decline during the 1990s, English sole biomass

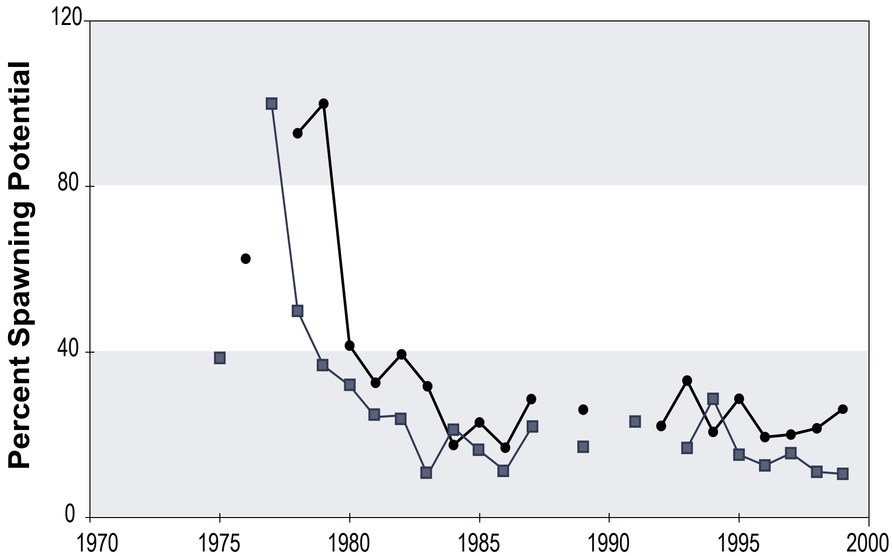


Figure 2-27. Copper rockfish spawning potential in Puget Sound. Spawning potential of copper rockfish in Puget Sound has dropped significantly since the late 1970s and continues to remain low. (Source: WDFW)

● North
■ South

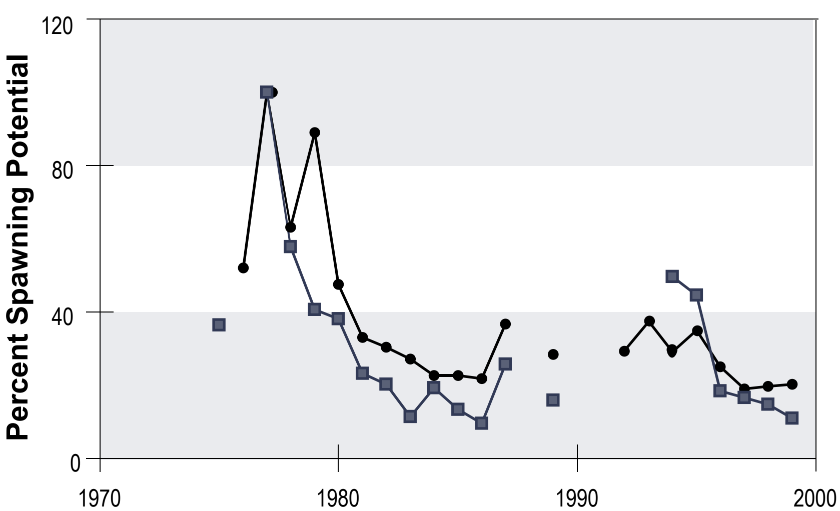


Figure 2-28. Quillback rockfish spawning potential in Puget Sound. Spawning potential of quillback rockfish in Puget Sound has dropped dramatically since the late 1970s and has continued to decline in recent years. (Source: WDFW)

● North
■ South

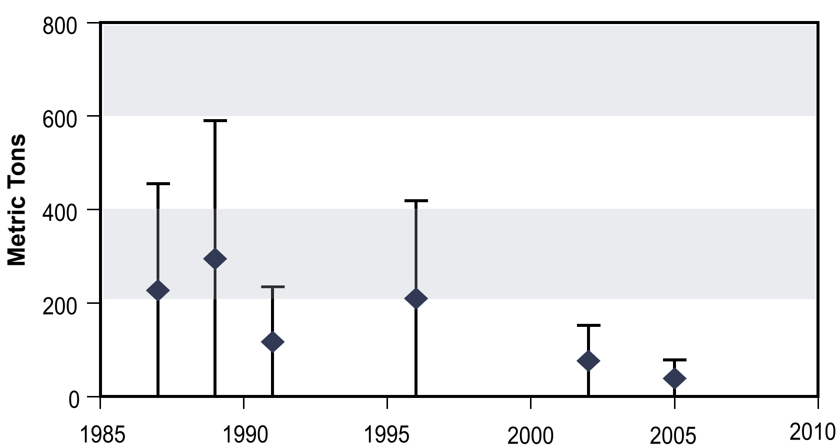
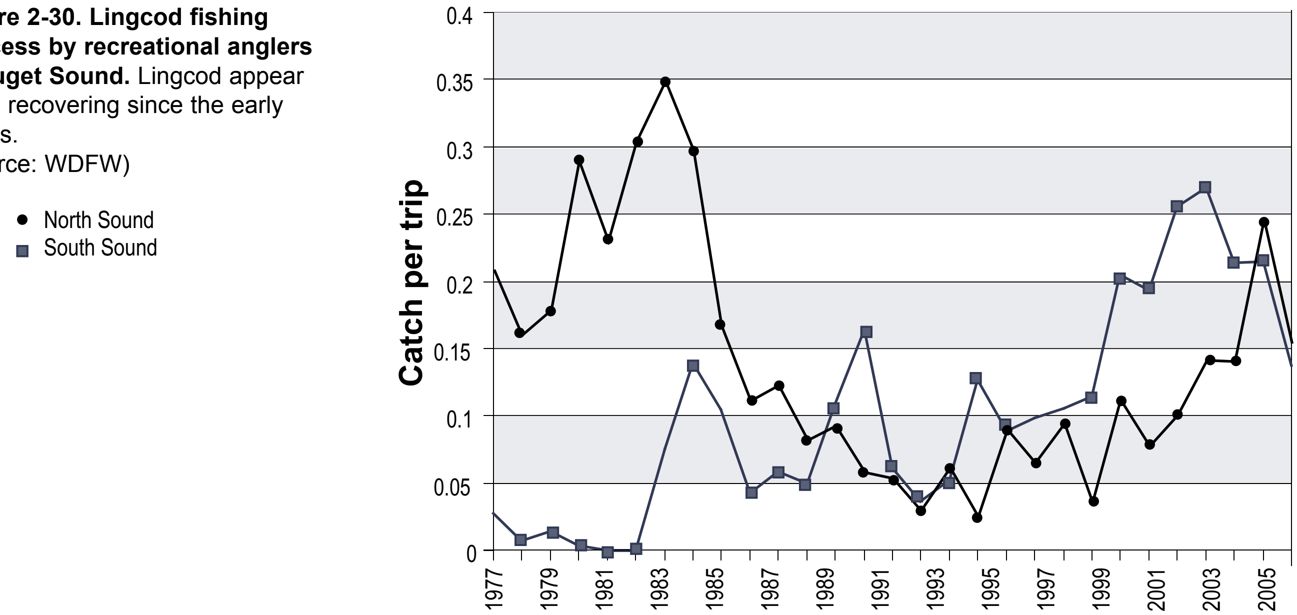


Figure 2-29. Quillback rockfish biomass in south Sound. The biomass of quillback rockfish, as determined by bottom-trawl surveys, indicates the continued decline in this species in South Puget Sound. (Source: WDFW)

Figure 2-30. Lingcod fishing success by recreational anglers in Puget Sound. Lingcod appear to be recovering since the early 1990s.
(Source: WDFW)



in the south Sound has recovered to levels observed in the late 1980s. Recent survey biomass is now 17 percent above the long-term average. Starry flounder and sand sole are in average and above-average abundances, but long-term declines of rock sole and Dover sole have resulted in below-average and depressed stock status for these species.

Impacts to the Ecosystem

The reasons for the declines of groundfish species are complicated because the cause-and-effect relationships are difficult to establish and many suspected stressors have been simultaneously at play. Pacific cod and walleye pollock populations are the most southerly distributed groundfish that occur along the West Coast, and warmer Puget Sound temperatures may be suppressing their spawning success. Spiny dogfish and rockfishes share life history characteristics, including delayed maturity, slow growth rates, and longevity that make them vulnerable to fishing pressure. The dramatic differences in abundance and size of rockfishes from marine reserves and fished areas in Puget Sound strongly support the conclusion that fishing controls the abundance, size and structure of populations and may be responsible for the declines of once-commonly caught species. Other stressors to fish populations may be acting in concert with more direct stressors. Toxic compounds have been shown to be prevalent in English sole and rockfish and may alter these fishes' success at reproduction and growth. How all these stressors interact is not known; however, there appear to be long-term changes in the community and trophic structure of groundfishes in Puget Sound. In the north Sound, the overall abundance of groundfish has not changed since 1987, but codfishes, other groundfish, and dogfish have become less abundant, while flatfishes have increased in biomass (Figure 2-31). In the south Sound, biomass was lower in 1989 and 1991 but, more recently, has been comparable to the 1987 level. However, over time, codfishes and dogfish have become extremely low in abundance, with a concomitant increase in ratfish. Whether or how the trophic structure is changing is not yet understood, but it has been suggested that declines in cod and dogfish, which feed on juvenile crabs and fishes, may have released ratfish, flatfishes, and Dungeness crab from predation pressure or limited food resources, enabling these fishes to increase in abundance.

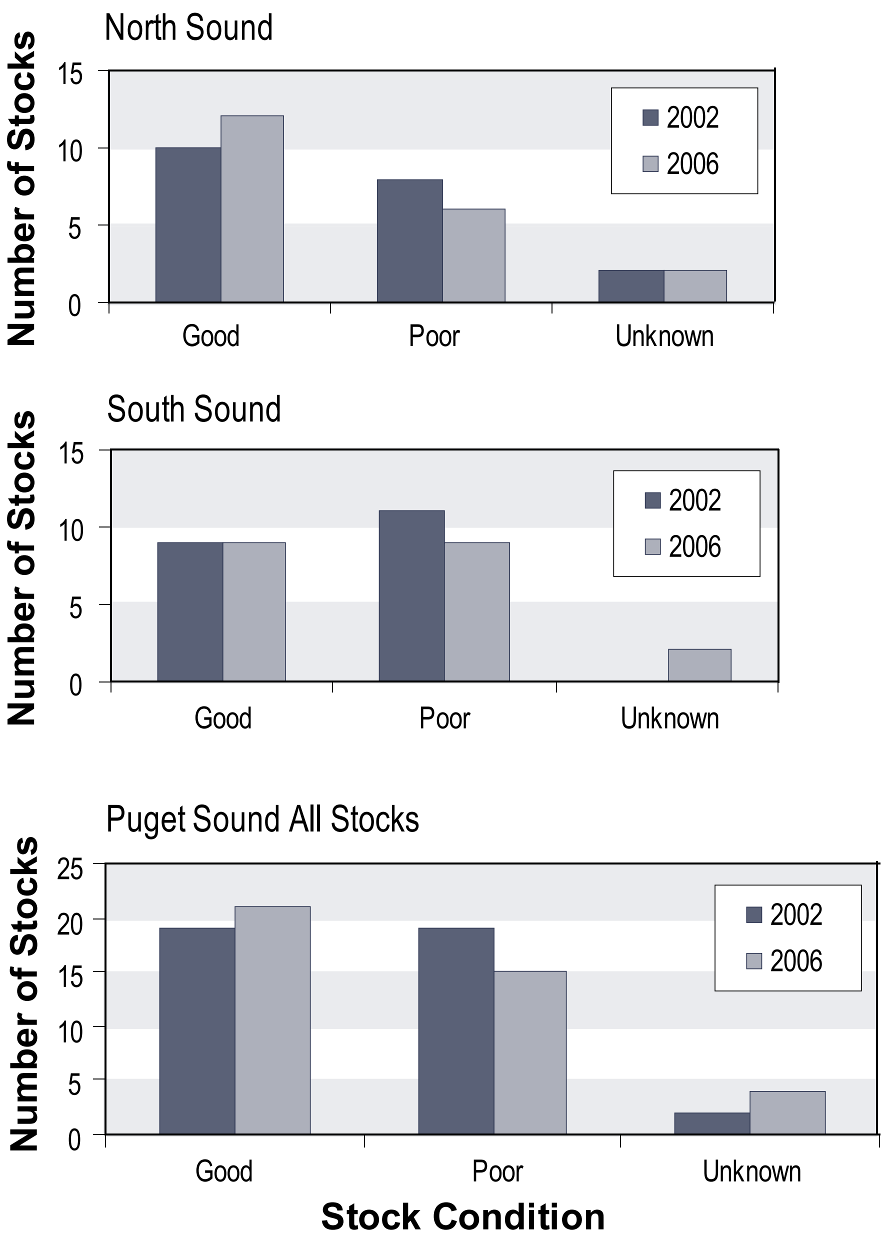


Figure 2-31. Groundfish stock conditions 2002-2006 north Sound and south Sound. Ratfish have increased in South Sound, although dog fish and cod have declined throughout Puget Sound. Flatfish remain fairly steady in south Sound and have increased in abundance in north Sound. (Source: WDFW)

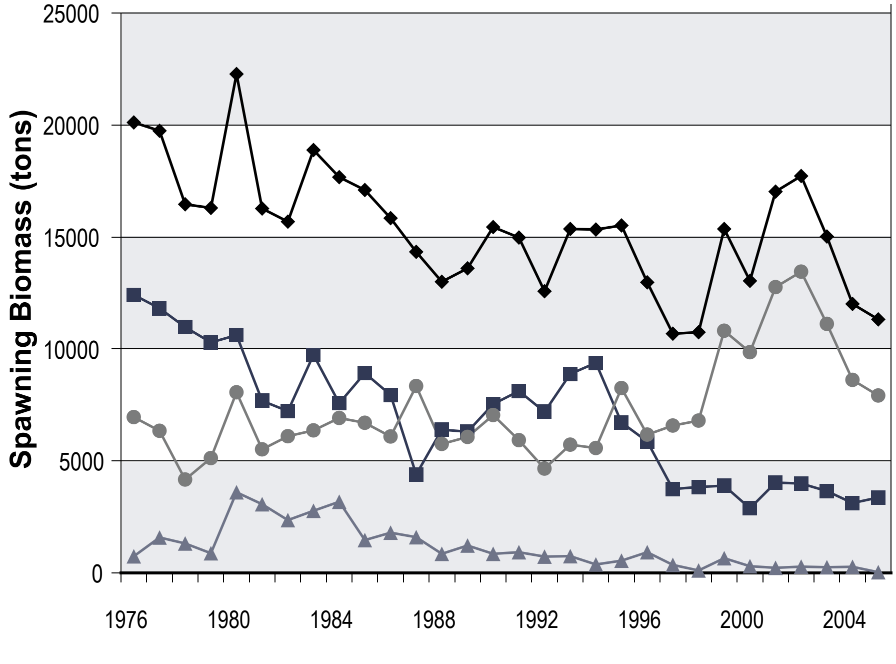
b. Forage Fish in Puget Sound

Forage fish are small schooling species that are important food organisms for a wide variety of animals, including seabirds, marine mammals, and predatory fish. They feed mainly on zooplankton and phytoplankton and reside in the upper levels of the water column and in nearshore areas.

i. Pacific Herring

WDFW recognizes 19 different stocks of Pacific herring (*Clupea pallasi*) in Puget Sound, based primarily on the timing and location of spawning activity. Annual herring spawning biomass is estimated for each stock using spawn deposition surveys and acoustic-trawl surveys. Spawn deposition surveys provide a direct estimate of herring spawning biomass. Marine vegetation on spawning grounds is

Figure 2-32. Estimated spawning biomass of Puget Sound herring by region, 1976 to 2005. Most herring stocks in Puget Sound have declined in the past five years. For some stocks (north Sound and the Straits), this is a continuation of a longer-term decline, while for other stocks (in the central and south Sound) this decline follows a variable trend of stock increases and declines. The force behind this decline is not well understood and may be due to a combination of changing ocean conditions, degraded water quality, nearshore habitat loss, and other factors. (Source: WDFW)



sampled for the location of spawn deposition and spawn density, and those data are converted to an estimate of spawning escapement. Acoustic-trawl surveys are conducted in the areas where spawners aggregate early in the spawning season, when pre-spawner abundance is peaking.

Status and Trends

The cumulative abundance of spawning herring in Puget Sound has decreased since 2002, when the total reached 17,700 tons (Figure 2-32). This total reflects the trend exhibited by the combined biomass of south and central Puget Sound herring stocks, which increased from 1997 to 2002, then decreased through 2005.

In northern Puget Sound, herring stocks have remained suppressed, primarily because of the continued critical status of the Cherry Point herring stock. Recent research has indicated that the Cherry Point herring population is genetically distinct from other Puget Sound and British Columbia herring stocks. However, a review by NOAA in 2005 concluded that this stock did not meet the ESA criteria

Focus Study

Sixgill shark study in Puget Sound

WDFW, in partnership with the National Marine Fisheries Service (NMFS), has been conducting basic biological research on sixgill sharks (*Hexanchus griseus*) in Puget Sound since 2003. This research is oriented towards obtaining basic biological knowledge on the abundance, age, geographical distribution, and movements of these sharks within Puget Sound. Sixgill sharks have been captured with longline fishing gear and tagged with visual external tags or internal acoustic tags. The Seattle Aquarium is also conducting a companion study in Elliott Bay.

Between 2003 and 2005, 291 sixgill sharks have been captured. Of these, 262 have been tagged with visual tags and 22 tagged with both visual and acoustic tags. All of the fish encountered to date have been juveniles, averaging nearly seven feet in length. (Adults can exceed 15 feet (4.6 m) in length.) Despite extensive searches in the central and south Sound, Admiralty Inlet, and the San Juan Islands, no sexually mature adult has been detected. Preliminary results of the acoustical tagging indicate that the juveniles are resident in Puget Sound, making few long-distance movements out of the Sound.

Little is known about the behavior and ecological function these large, predatory fish have in Puget Sound's food web. They may be an important apex predator that plays a role the population dynamics of other species.

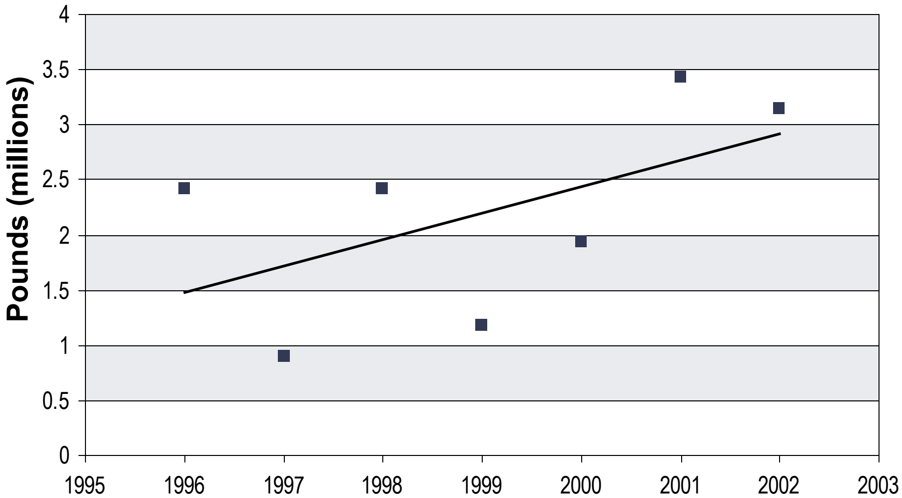


Figure 2-33. Estimated annual catches of surf smelt by recreational fishing, 1995 to 2002. While catch loads have been steadily increasing, little is known about the overall abundance of this species or its ecological functions. (Source: WDFW)

as a distinct population segment. The estimated spawning biomass for this stock decreased from 3,095 tons in 1996 to a low of 808 tons in 2000, followed by an encouraging, if modest, rise to 2,010 tons in 2005. This particular stock has been variable in size, ranging from 3,100 tons to nearly 15,000 tons between 1973 and 1995. While the recent increases in abundance are encouraging, the stock remains a focus of concern.

Herring spawning biomass levels in the Strait of Juan de Fuca region are also low. Following a peak spawning biomass of 3,200 tons in 1980, the Discovery Bay herring stock has decreased dramatically and steadily. Recent spawning biomass levels have been between 200 tons and 250 tons per year. Currently, the Dungeness/Sequim Bay stock is also at a very low level of abundance.

Impacts to the Ecosystem

Because of the ecological and economical importance of herring in Puget Sound, several studies have attempted to determine causes of declining abundance, especially in northern Puget Sound. These studies have found several potential causes of decline, including increased incidence of disease, chemical contamination, and larval deformities.

ii. Surf Smelt

Surf smelt (*Hypomesus pretiosus*) is a species of forage fish that utilizes intertidal habitat for spawning. Surf smelt deposit their eggs onto beaches at high tide where they incubate for several weeks prior to hatching. Because of the vulnerability of the spawning habitat to human destruction, management efforts have focused on identification and protection of surf smelt spawning areas.

Status and Trends

Little is known of the abundance of surf smelt in Puget Sound. However, surf smelt is harvested by both commercial and recreational fishing and catch sizes may give some indications of the fish's abundance. Between 1993 and 2002, annual catches of surf smelt averaged 295,000 pounds; 40 percent of this amount has been taken in commercial fisheries. Recreational catches in recent years have been variable but generally increasing (Figure 2-33). Recreational fishing for surf smelt receives considerable interest; surf smelt is the most common marine fish species caught by Puget Sound's recreational fishers.

iii. Northern Anchovy
Northern anchovies (*Engraulis mordax*) have appeared in south Puget Sound over the past decade and their geographic distribution and abundance seems to be expanding. Recent reports from many parts of the central and south Sound indicate prevalence of post-larval anchovies, approximately 1.2 inches (30 mm) in size, in the nearshore in late summer and early fall, with juvenile and adult fish in the 4-10 inch (100 mm to 150 mm) size range visible in offshore waters throughout much of the year. Anchovies are known to be pelagic multiple spawners, with newly hatched larvae living among the plankton for about three months before reaching a post-larval life stage.

Sizable schools of juvenile anchovies attract overwintering birds, especially double-crested cormorants, grebes, and mergansers, as well as harbor seals and, presumably, salmon, cutthroat trout, and dogfish and other mid-water and surface-feeding fish. Further research is needed to understand the importance of this species as a major component of the food web in the south and central Sound and southern Hood Canal, where this species has also been sighted in recent years. Recently, a multi-agency research effort has begun to design a comprehensive forage fish study to address bio-energetics, seasonal migration and distribution, disease prevalence, and relative abundance of major forage fish species, including herring, surf smelt, Pacific sand lance, and anchovies.

a. Pelagic Fish

i. Market Squid
Market squid (*Loligo opalescens*) are cephalopods, about 6 to 10 inches (152.4-254 mm) long, with eight sucker-laden arms and two tentacles. They are nocturnally active predators in Puget Sound that travel in large schools and forage in mid-water. Market squid are generally believed to live for only one or two years. There is some indication that dense spawning congregations occur in Puget Sound, but it is not clear how frequently. It is unknown if the squid remain in the Sound for their entire lives or move out into the open ocean during certain months. At present, there is no active monitoring of squid in Puget Sound; thus, their population size is unknown and may fluctuate greatly from year to year.

Status and Trends
Only harvest records provide an indication of market squid abundance. The commercial squid fishery is presently at a low level, with peak harvest taken only when abundance is high. About 3,000 pounds (1,361 kg) per year of commercial harvest have been documented since the 1950s, with some years showing no harvest at all (Figure 2-34). In the 1990s, harvests rose above the average, with over 16,000 pounds (7,256 kg) taken in 1994, 25,000 pounds (11,339 kg) taken in 1995, and about 10,000 (4,536 kg) pounds taken in 1996. Since 1996, no landings have been recorded, except for 1,000 (454 kg) pounds taken in 2004.

ii. Salmonids
Puget Sound salmonids include salmon, steelhead, and rainbow trout (coastal cutthroat trout, bull trout). WDFW, Washington tribes, and federal agencies (NMFS and USFWS) have examined the status of Puget Sound salmonids in 1992 and again in 2002. The results of state, tribal, and federal status assessments of Puget Sound salmonids are presented in this section.

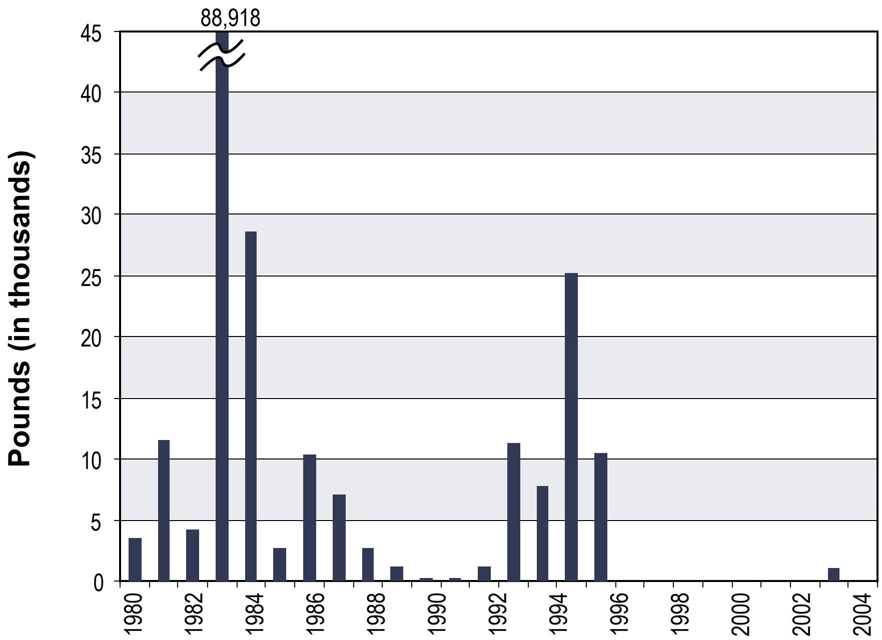


Figure 2-34. Annual commercial landings of market squid from Puget Sound, 1980 to 2004. No abundance data have been collected for squid, so harvest loads and casual observations are the only estimates of abundance. (Source: WDFW)

Status and Trends

A state/tribal assessment of salmon and steelhead status was first conducted in 1992. Results were published in the Salmon and Steelhead Stock Inventory (SASSI), which identified independent stocks (WDFW et al. 1993). The status of each stock was rated as healthy, depressed, critical, unknown, or extinct. Healthy status means that stock abundance shows no pronounced negative trends in recent years, is consistent with available habitat, and is within the range of natural variation in survival for the stock. Depressed means that abundance is declining or is lower than expected, based on available habitat and natural variation in survival, but not so low that permanent genetic damage (loss of genetic diversity) is thought to have occurred. Critical also reflects declining or chronically low abundance, but to a degree that permanent genetic damage is thought to have occurred or is imminent. Stock status is unknown when there are inadequate abundance data to rate status with confidence. Extinct stocks are those that are no longer present in their historical range, and whose disappearance has been documented by state, tribal, federal, or other professional fish biologists. The number of extinct stocks is probably greater than documented.

Table 2-4 presents the numbers of Puget Sound salmonid stocks by region and status in both 1992 and 2002. The north Sound region includes streams west of the Cascade Crest from the Canadian border south through the Snohomish River system. The south Sound includes streams from the Lake Washington system south and on the east side of the Kitsap Peninsula. Hood Canal includes streams south of the Hood Canal Floating Bridge on both the east shore of the Olympic Peninsula and the west shore of the Kitsap Peninsula. The Strait of Juan de Fuca includes streams north of the Hood Canal Floating Bridge and west along the strait to Cape Flattery.

The number of Puget Sound chinook (*Oncorhynchus tshawytscha*) stocks was reduced from 29 in 1992 to 27 in 2002, because of changes in the Snohomish River basin and Hood Canal stock lists. The number of healthy stocks declined from 10 to four, while the number of depressed and critical stocks increased from

Table 2-4. Status of Puget Sound salmonid stocks in 1992 and in 2002.

[1] The status of one South Sound chinook stock was not rated in 2002, which accounts for the difference in the number of stocks and the numbers of stocks with SaSI ratings in 2002 (27 vs. 26).

[2] The status of one South Sound steelhead stock was not rated in 2002, which accounts for the difference in the number of stocks and the numbers of stocks with SaSI ratings in 2002 (60 vs. 59)

Region	Total Stocks		Healthy		Depressed		Critical		Unknown		Extinct	
	1992	2002	1992	2002	1992	2002	1992	2002	1992	2002	1992	2002
Chinook												
North Sound	15	13	3	1	7	9	2	2	3	1	0	0
South Sound[1]	10	9	5	3	0	2	1	1	4	2	0	0
Hood Canal	1	2	1	0	0	1	0	1	0	0	0	0
Strait	3	3	1	0	1	2	1	1	0	0	0	0
Total	**29**	**27**	**10**	**4**	**8**	**14**	**4**	**5**	**7**	**3**	**0**	**0**
Chum												
North Sound	12	12	8	8	0	0	0	0	4	4	0	0
South Sound	23	23	18	17	0	1	0	0	4	4	1	1
Hood Canal	12	22	10	10	0	4	1	1	1	1	0	6
Strait	8	10	2	1	1	2	1	1	4	5	0	1
Total	**55**	**67**	**38**	**36**	**1**	**7**	**2**	**2**	**13**	**14**	**1**	**8**
Coho												
North Sound	14	14	4	8	3	0	0	0	7	6	0	0
South Sound	11	10	8	6	3	3	0	1	0	0	0	0
Hood Canal	9	9	4	6	5	1	0	0	0	2	0	0
Strait	12	12	4	6	5	2	1	1	2	3	0	0
Total	**46**	**45**	**20**	**26**	**16**	**6**	**1**	**2**	**9**	**11**	**0**	**0**
Pink												
North Sound	7	5	5	5	0	0	0	0	2	0	0	0
South Sound	2	2	2	0	0	1	0	0	0	1	0	0
Hood Canal	3	3	2	1	1	2	0	0	0	0	0	0
Strait	3	3	0	0	1	1	2	2	0	0	0	0
Total	**15**	**13**	**9**	**6**	**2**	**4**	**2**	**2**	**2**	**1**	**0**	**0**
Sockeye												
North Sound	1	1	0	1	0	0	1	0	0	0	0	0
South Sound	3	3	0	1	3	2	0	0	0	0	0	0
Hood Canal	0	0	-	-	-	-	-	-	-	-	-	-
Strait	0	-	-	-	-	-	-	-	-	-	-	-
Total	**4**	**4**	**0**	**2**	**3**	**2**	**1**	**0**	**0**	**0**	**0**	**0**
Steelhead												
North Sound	22	22	7	3	3	6	1	0	12	12	0	0
South Sound[2]	13	13	7	1	1	5	0	1	5	5	0	0
Hood Canal	11	11	0	0	5	6	0	0	6	5	0	0
Strait	14	14	2	4	6	3	0	0	6	8	0	0
Total	**60**	**60**	**16**	**8**	**14**	**20**	**1**	**1**	**29**	**30**	**0**	**0**

Region	Total Stocks	Healthy	Depressed	Critical	Unknown	Extinct
			1998 Status Assessment			
Bull Trout / Dolly Varden						
North Sound	9	2	0	0	7	0
South Sound	6	0	0	0	6	0
Hood Canal	3	1	0	0	2	0
Strait	4	1	0	0	3	0
Total	**22**	**4**	**0**	**0**	**18**	**0**
			2000 Status Assessment			
Coastal cutthroat trout						
North Sound	8	1	0	0	7	0
South Sound	4	0	0	0	4	0
Hood Canal	2	0	0	0	2	0
Strait	3	0	0	0	3	0
Total	**17**	**1**	**0**	**0**	**16**	**0**

eight to 14 and from four to five, respectively. Increased abundance data resulted in the number of unknown stocks declining from seven to three.

The number of Puget Sound chum (*Oncorhynchus keta*) stocks increased from 55 to 67 between 1992 and 2002, following state/tribal re-examination of summer chum stocks in Hood Canal and the Strait of Juan de Fuca that resulted in the addition of 12 stocks, including eight known to have become extinct (WDFW and PNPTC 2000). The number of healthy stocks decreased slightly, from 38 to 36, while the number of depressed stocks increased from one to seven, due mainly to the addition of summer chum stocks in Hood Canal and the Strait. There was no change in the number of critical stocks. The number of stocks of unknown status increased from 13 to 14, because of the addition of a new summer chum stock (Dungeness summer chum) in the Strait, for which abundance data are lacking.

Puget Sound coho (*Oncorhynchus kitsutch*) stocks decreased from 46 to 45 between 1992 and 2002 because the Newaukum Creek stock (Green River tributary) was combined with the Green River/Soos Creek stock. The number of healthy stocks increased from 20 to 24 while the number of depressed stocks decreased from 16 to six. The number of critical stocks increased slightly from one to two. The number of stocks of unknown status increased from nine to 11.

The number of Puget Sound pink salmon (*Oncorhynchus gorbuscha*) stocks decreased from 15 to 13 between 1992 and 2002. Genetic analysis indicated that North Fork/Middle Fork Nooksack pinks were not genetically distinct from South Fork Nooksack pinks, so those two stocks were combined into a single Nooksack stock. Similarly, genetic analysis showed no difference between the North Fork and South Fork Stillaguamish pink stocks, and they were also combined into a single Stillaguamish stock. The number of healthy stocks declined from nine to six, and the number of depressed stocks increased from two to four. There was no change in the number of critical stocks. The number of stocks of unknown status decreased from two to one.

Sockeye (*Oncorhynchus nerka*) stocks in Puget Sound did not change between 1992 and 2002. The number of healthy stocks increased from none to two, and there were corresponding decreases in the number of depressed and critical stocks.

There was no change in the number of Puget Sound steelhead (*Oncorhynchus mykiss*) stocks between 1992 and 2002. The number of healthy stocks decreased from 16 to eight. The number of depressed stocks increased from 14 to 20. The number of critical stocks was unchanged. The number of unknown stocks increased from 29 to 30.

Bull trout (*Ssalvelinus confluentus*) and Dolly Varden (*Salvelinus malma malma*) have been combined because they are difficult to distinguish from one another. Rather esoteric morphological differences have been identified, but WDFW biologists have found that these differences are not reliable statewide. Abundance data on additional stocks have been collected since 1998; however, the inventory has not been revised.

As with bull trout/Dolly Varden information, abundance data are largely lacking for Puget Sound coastal cutthroat. As such, the status of most cutthroat stocks is unknown.

In addition to state/tribal status assessments, NMFS undertook extensive status reviews of West Coast salmon (Myers et al. 1998, Weitkamp et al. 1995, Hard et al. 1996, Johnson et al. 1997, Gustafson et al. 1997), steelhead (Busby et al. 1996),

Table 2-5. ESA status of Puget Sound salmonid species as of 2005.
(Source: WDFW)

Distinct Population Segment (DPS) or Evolutionarily Significant Unit (ESU)	ESA Status	Date of Listing
Puget Sound Chinook ESU	Threatened	March 1999
Puget Sound/Strait of Georgia Chum ESU	Not Listed	
Hood Canal Summer-Run Chum ESU	Threatened	March 1999
Puget Sound/Strait of Georgia Coho ESU	Not Listed	
Odd-Year Pink ESU	Not Listed	
Even-Year Pink ESU	Not Listed	
Baker River Sockeye ESU	Not Listed	
Puget Sound Steelhead DPS	Proposed Threatened	March 2006
Coastal-Puget Sound Bull Trout DPS	Threatened	November 1999
Puget Sound Coastal Cutthroat Trout DPS	Not Listed	

and cutthroat trout (Johnson et al. 1999) in the mid to late 1990s, in response to a number of petitions to list these species as threatened or endangered under the federal ESA. The status for chinook, chum, coho, pink, sockeye, steelhead, and coastal bull and cutthroat trout are listed in Table 2-5. ESU stands for Evolutionarily Significant Unit and DPS is Distinct Population Segment. They are both terms that identify ESA listable units that are smaller than an entire species.

8. Marine Birds

Over 100 species of marine birds rely on Puget Sound's marine food web during some or all of their life histories. Since the early 1970s, approximately 30 percent of these species have been researched for PSAMP by scientists at WDFW, Washington University, and other agencies and organizations. Studies have focused on population surveys, foraging habits, contamination levels, and dispersal patterns. Research has also been conducted to assess overall population densities for major species of marine birds utilizing Puget Sound's marine food web.

The following section reports on overall marine bird density status and trends according to several monitoring and research programs. It is followed by an overview of the status and trends of individual bird species that are currently monitored or have been recently surveyed in Puget Sound.

What is a marine bird?

Marine bird is an umbrella term for seabirds, seaducks, and shorebirds.

Seabirds (excluding waterfowl) frequent coastal waters and the open ocean. Examples are gulls, murres, pelicans, cormorants, and albatrosses.

Seaducks are diving ducks that frequent the sea, such as scoters, harlequins, long-tailed ducks, and mergansers.

Shorebirds are any birds that frequent the seashore, such as western sandpipers and black oystercatchers.

a. Overall Marine Birds

The first comprehensive effort to assess overall marine bird populations in Puget Sound was the Marine Ecosystems Analysis (MESA) in 1978 and 1979. MESA was administered by NOAA with funding from EPA. MESA researchers used a variety of techniques to assess overall bird densities, including population counts from over 100 shore-based sites, transect counts from ferries and small boats, breeding island counts, and aerial surveys.

The next comprehensive marine bird survey was conducted between 1992 and 2000 by PSAMP scientists from WDFW, who mounted twice-yearly aerial population surveys to monitor wintering nearshore marine birds. They then compared density estimates from a subset of their survey transects with the nearly identical MESA aerial survey transects. Results from this comparison showed a mixture of changes that ranged from significant decreases (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed ducks, and brant) to stable or more slowly decreasing patterns (goldeneyes, buffleheads, and gulls) and some increasing trends (harlequin ducks and, probably, mergansers) (PSAT 2002).

Birds that have declined by 20 percent or more since 1970s:	Species that have increased by 20 percent or more since the 1970s:
Pacific and Red-throated Loons	Common Loon
Western Grebe	Double-crested and Pelagic Cormorant
Red-necked and Horned Grebes	Great Blue Heron
Brandt's Cormorant	Bald Eagle
Common Murre	Pigeon Guillemot
Marbled Murrelet	Rhinoceros Auklet
Bonaparte's and Heermann's Gull	White-winged Scoter
Black Brant	Harlequin Duck
Surf Scoter	Common Merganser
Scaup species combined composed largely of Greater Scaup	Northern Pintail
Ruddy Duck	American Widgeon
Long-tailed Duck	
Common and Barrow's Goldeneye	
Mallard	

Table 2-6. Changes in marine birds and ducks in northern Puget Sound between the 1970s and 2003–2005. These estimates are derived by comparing MESA land-based and ferry-based surveys with WWU surveys (Bower et al. unpubl.). (Source: WDFW)

Between 2003 and 2005, scientists from Western Washington University (WWU), with funding from Washington Sea Grant and other sources, conducted a marine bird census that closely replicated the 1970s MESA research. WWU scientists, with help from students and volunteers, conducted monthly land and water surveys between September and May in the inner marine waters of north Puget Sound and south Georgia Straits. The observed species trends from the WWU census were similar to those previously reported by PSAMP, with the exception of double-crested cormorant, pigeon guillemot, common loons and harlequin ducks (Figure 2-35). Some of the differences in monitoring trends between PSAMP and WWU might be an artifact of combining migration and wintering populations. Combined with the 1992-2000 PSAMP surveys (Nysewander et al. 2001), these new data from WWU provide additional trend information on the overall marine bird abundance in Puget Sound for a 25-year period.

Based on the WWU survey, the total number of marine birds in Puget Sound has declined by 27 to 47 percent overall[6] since the MESA surveys in the 1970s. Of the 30 most common species in the 1970s, 19 declined by 20 percent or more (Table 2-6).

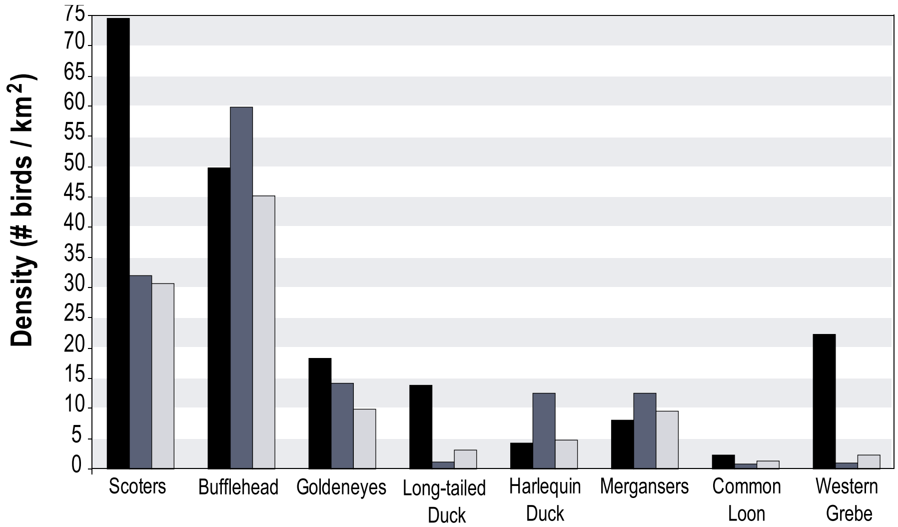
It is not entirely clear what is driving the decline in marine birds, although researchers point to a variety of known and/or likely factors, including pollution, climate change, non-native species, collisions with man-made structures, derelict fishing gear, some fishing practices, prey unavailability, and loss of habitat.

Impacts to the Ecosystem

Increases and decreases in marine bird densities in Puget Sound are difficult to connect quantitatively to specific ecosystem impacts. However, some work has been done linking declines in forage fish populations, particularly the Cherry Point herring stock, to fattening rates in surf scoters. In other species, it is assumed that declining forage fish populations would force avian predators to switch to other marine organisms or habitats and would put greater predator pressure on those resources. Fewer avian predators would possibly reduce mortality aspects related to some depressed stocks of forage fish or some standing stocks of shellfish. Presently, it is unknown how these decreases play out in the marine ecosystem (i.e., whether they are causes or effects).

[6] Observations during the September - May period are combined. This is somewhat problematic, because migration and wintering groups are lumped together.

Figure 2-35. Marine bird populations in Puget Sound based on three surveys between 1970 and 2004. Surveys indicated major declines in scoters, goldeneyes, long tailed ducks and western grebes. The causes of these declines are not known, as most marine ducks spend only a portion of the year in the Puget Sound region.
(Source: WDFW)



* More sites sampled than in previous surveys.

b. Scoters

Puget Sound attracts some of the largest wintering scoter populations on the west coast of North America (Wahl et al. 1979). Puget Sound is also one of the three most important staging areas and one of the two major molting areas for other West Coast populations, including scoters that winter in California, Mexico, and British Columbia.

Puget Sound's scoter populations, including the wintering, staging, and molting populations, consist primarily of surf scoters (*Melanitta perspicillata*) and white-winged scoters (*Melanitta fusca*). Black scoters (*Melanitta perspicillata*) are also present, but in much smaller numbers. Scoters spend eight to 10 months in marine waters, then migrate to the Canadian interior to breed on freshwater lakes. Washington's wintering scoters spend from eight to 10 months in marine waters, with males spending approximately a month longer than females. Scoter populations have dropped precipitously in the past 25 years. Studies are underway to determine the causes of the declines and to assess out how different West Coast subpopulations are faring.

Scoters use a broad range of foraging habitats. They have been observed feeding on newly settled mussel beds, foraging in soft substrates inhabited by clams and other shellfish, and feeding on shorelines on which forage-fish roe has been deposited. Additional observations suggest they may be feeding on organisms such as shrimp, euphausids, and sand lance, that are highly clumped.

Since 2003, WDFW researchers have tracked wintering populations of scoters from British Columbia and Washington using both satellite and VHF radio transmitters. These technologies helped gather information on migration routes as well as local breeding and molting grounds for scoters from Washington and British Columbia. Understanding the scoters' local and large-scale movements and their use of habitat throughout the year will help direct management activities to restore populations.

Status and Trends

Based on historic surveys (Wahl et al. 1981) and WDFW's annual monitoring program initiated in 1992, densities for all three scoter species in Puget Sound nearshore waters have declined as follows: surf scoters, 64 percent; white-winged scoters, 33 percent; and black scoters, three percent. Collectively, these populations

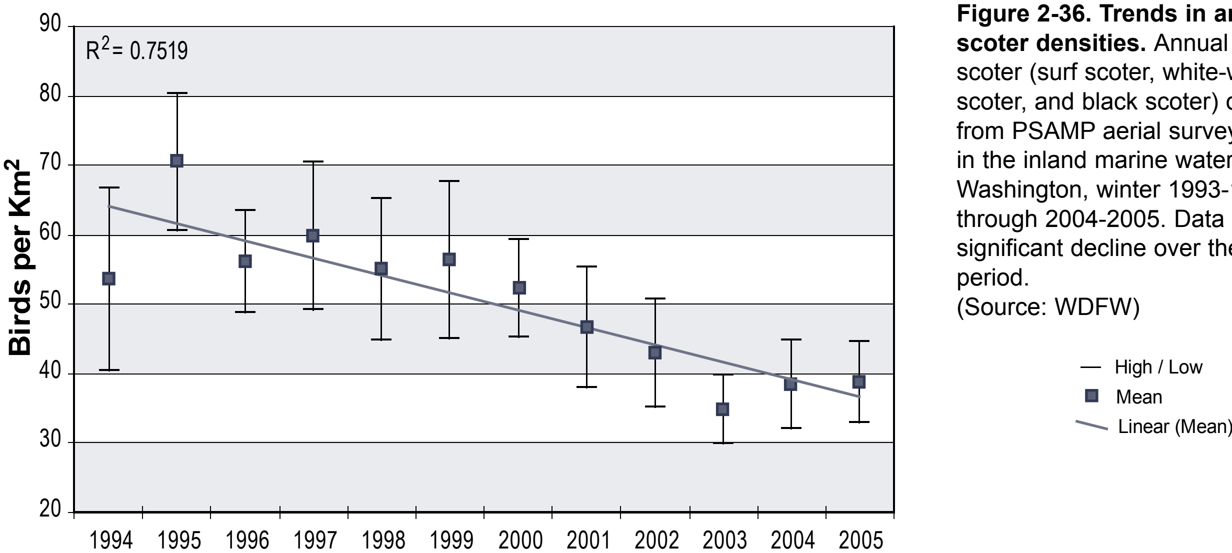


Figure 2-36. Trends in annual scoter densities. Annual winter scoter (surf scoter, white-winged scoter, and black scoter) densities from PSAMP aerial surveys in the inland marine waters of Washington, winter 1993-1994 through 2004-2005. Data show a significant decline over the 12-year period.
(Source: WDFW)

declined by approximately 57 percent between 1978 and 1999. This decline has continued between 1999 and 2005 (Figure 2-36) in most all of the subregions of Puget Sound (Evenson et al. 2002, Nysewander at al. 2003, 2004-05 WDFW aerial survey results). This decrease represents the largest decline in biomass of marine birds in Puget Sound over the past 25 years, although some other species, such as the western grebe, lost a larger percentage of their original populations. Studies are underway to determine the causes of the decline and to assess how Washington subpopulations are faring.

In 2003, WDFW began tracking white-winged scoters to better understand their dispersal patterns. The program was expanded in 2004 to include surf scoters. By March 2006, WDFW had deployed 94 VHF radio transmitters[7] on 91 surf scoters and three white-winged scoters and 73 satellite transmitters[8] on 47 surf scoters and 26 white-winged scoters. In addition, approximately 200 scoters were captured, examined, and banded each year of the four-year study.

Researchers tracked scoters to their spring breeding and molting areas and back to their wintering areas in Puget Sound, with the following results: 13 percent of the birds died on the breeding grounds or on return migration, and 87 percent returned to the Puget Sound region to winter again. Of those returning, 89 percent returned to the exact same wintering site frequented the previous winter, and 11 percent returned to within 30 to 50 miles of their previous wintering sites. The scoters fitted with the more location-precise VHF transmitters also exhibited high degrees of fidelity to winter sites.

Almost exclusively, Washington's scoter populations migrate to breed in Canada's boreal forest region. This is an area that stretches from the Great Bear Lake to Great Slave Lake and Lake Athabaska in the Northwest Territories. Satellite and radio-tracking data indicate that the greatest declines of breeding scoters are occurring in this region. Figure 2-37 shows how this region's breeding scoters have declined more than in other scoter breeding areas, such as in Alaska.

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[7] VHF transmitters are able to measure locations much more precisely than satellite transmitters. However, if a bird disappears (i.e., the signal is lost), researchers cannot determine the cause (mortality, lost transmitter, etc.).

[8] Satellite transmitters have mortality signals and temperature gauges and thus enable researchers to understand exactly what happens to each bird. However, these transmitters are less precise in determining location.

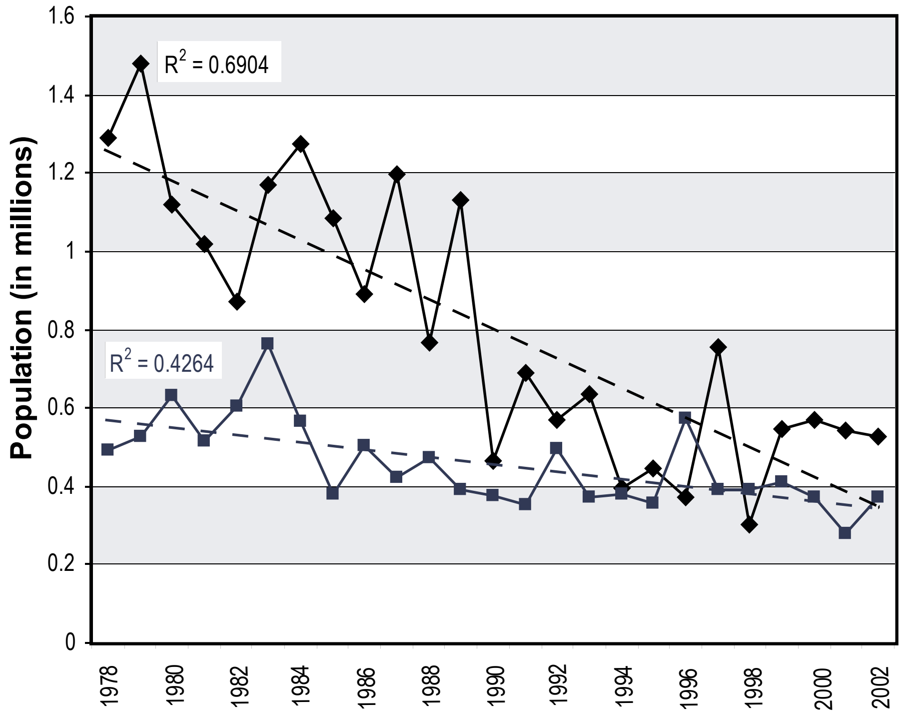


Figure 2-37. Trends in yearly breeding scoter populations from USFWS aerial surveys in the Canadian Interior and Alaska, 1978-2002. Trend lines are derived from different breeding strata used by scoters, defined by geographic area. The "not Washington strata" include California birds, Oregon birds, and British Columbia birds. Scoters are not declining uniformly across their whole range but are declining more in the center of their range (Puget Sound), which historically had the highest densities. The declines in breeding populations mirror the wintering scoter declines observed by the MESA (1978-1979) and PSAMP (1993-1999) aerial surveys (57 percent) . (Source: WDFW).

Recent tracking results suggest that Puget Sound surf scoters follow different migratory paths than do other surf scoters in the Pacific Flyway. (Nysewander and Evenson unpubl. data). The majority (65 percent) of Puget Sound's wintering scoter populations stage in Washington in the spring before heading to their breeding grounds. The remaining 35 percent do their spring staging in northern British Columbia or southeast Alaska, following the herring spawning events that occur at these locales later in the spring. In contrast, the majority of California's scoter population (80 to 85 percent) uses Southeast Alaska for their main spring staging areas. Most of the remaining populations use Puget Sound for their spring staging. This is also true for scoters from Baja, Mexico, and British Columbia, 14 to 17 percent of which use the spring staging areas in Washington. The spring staging areas in Puget Sound are located primarily between Padilla and Samish Bays in Skagit County and Boundary Bay at the mouth of the Fraser River.

Impacts to the Ecosystem

Scoters commonly feed on herring spawn, and recent declines in Puget Sound herring stocks (particularly the Cherry Point stock in north Puget Sound) may be affecting their foraging success.

c. Loons and Grebes

The six species of loons and grebes most common to the inner marine waters of Washington include the common loon (*Gavia immer*), Pacific loon (*Gavia pacifica*), red-throated loon (*Gavia stellata*), horned grebe (*Podiceps auritus*), red-necked grebe (*Podiceps auritus*), and western grebe (*Aechmophorus occidentalis*). All six of these species breed in freshwater habitats, though only four of the six (the western grebe, red-necked grebe, common loon, and, occasionally, the horned grebe) breed in Washington. A large number of coast loon and grebe populations spend a significant portion of the winter in Puget Sound, each species displaying a somewhat different distribution and habitat-use pattern. (Table 2-7)

Table 2-7. Distribution and habitat use of grebes and loons in Puget Sound.
(Source: WDFW)

Species	Distribution/habitat use
Horned grebes	Widely dispersed, closest to the shoreline.
Red-necked grebes	Dispersed in slightly deeper waters and tidal rips or eddies.
Western grebes	Seen in larger concentrations, most often in the highly concentrated resting flocks during the daytime. Feed over large areas in crepuscular or nocturnal periods.
Common loon	Disperses throughout the inner waters, usually in 1 or 2 pairs at any one place or time.
Pacific loon	Seen in larer flocks long tide rips,eddies, offshore banks, and other features that concentrate or direct the movement of forage fish schools.
Red-throated loon	Seen in larger flocks, typically in shallower nearshore waters.

Status and Trends

Monitoring results indicate that most Puget Sound loon and grebe species have declined significantly in recent years, with declines ranging from 64 to 95 percent (Nysewander et al. 2002) to 50 to 82 percent (Bowers et al. unpubl. data).

Historic and current breeding population levels for loons are not well known in Washington, with most of the available information dating from the past 15 years (Richardson et al. 2000). Surveys and mixed reports from 1979 to 1999 counted a total of 20 confirmed and 12 unconfirmed common loon nest sites in Washington. The densities of common loons are the lowest of all loon species (Figure 2-38) observed on Washington's marine waters during winter (Nysewander et al. 2002; recent unpubl. data). Although there has been some loon recovery on the marine waters in recent years, it is not evident from the most recent nesting surveys, which found that only 12 territorial pairs remain breeding in widely separated locations across the state. Of the approximately 32 breeding lakes in Washington, only eight were used for nesting in 2005 (Poleschook and Grumm , unpubl. data). The winter aerial surveys conducted by PSAMP from 1995 to 2005 indicated wintering common loons with the lowest density of all the loons but remaining fairly stable (Figure 2-38).

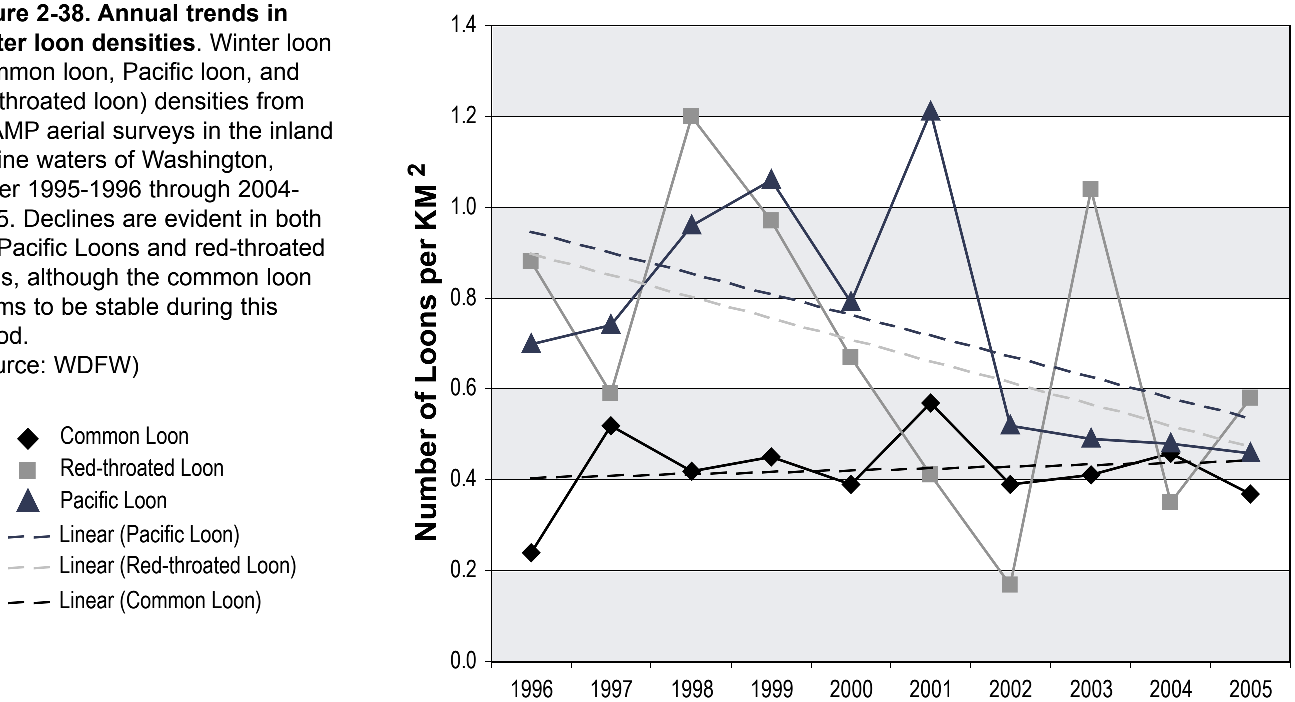
Focus Study

Seasonal Scoter Use of Herring Spawn and Eelgrass Habitat

Scoters congregate in dramatic numbers to consume herring spawn along much of the Pacific Ocean coast of North America, including Puget Sound. However, spawning activity in Puget Sound has declined substantially over recent decades. Surveys conducted in 2004 and 2005 by researchers from the University of Wyoming, involving captures and diet preferences, indicate that, when spawn is locally available, scoters consume little else. This same research indicates that spawn availability and scoter fattening rates are correlated. These studies also show that consumption of herring spawn for even a few days significantly increases scoters' fat reserves. The relative importance of spawn to scoters that are preparing for spring migrations and reproduction may depend on habitat characteristics of their winter foraging sites. Thus, availability of herring spawn in late winter and spring may be a limiting factor for scoters.

Research at 12 herring spawning areas in Puget Sound shows that surf scoters aggregate in greater numbers and are likely to travel greater distances to spawning events than are white-winged scoters. Eelgrass beds and their associated epifaunal prey are also important for scoters. At Padilla Bay, which contains 25 percent of Puget Sound's eelgrass beds and represents one of the 12 spawning areas surveyed, the number of scoters increased greatly and their fat reserves were more stable between early and late winter. At another surveyed area, Penn Cove bay, with mixed/hard substrates and little vegetation, both the numbers of scoters and the fat reserves on the birds declined substantially between early and late winter. Population surveys, telemetry data, and habitat characterizations are being used to evaluate whether eelgrass habitat and herring spawn play similar roles for scoters in bays throughout Puget Sound.

Figure 2-38. Annual trends in winter loon densities. Winter loon (common loon, Pacific loon, and red-throated loon) densities from PSAMP aerial surveys in the inland marine waters of Washington, winter 1995-1996 through 2004-2005. Declines are evident in both the Pacific Loons and red-throated loons, although the common loon seems to be stable during this period.
(Source: WDFW)



Wintering populations of Western grebes have declined in all wintering sites in Puget Sound covered by Christmas bird counts (Figure 2-39). The winter aerial surveys in western Washington 1994-2005 (Nysewander et al. unpubl.) also confirm the same type of decline in wintering numbers for Western grebes in the inner marine waters. This species exhibits the greatest percentage of decline (81 to 95 percent) over the last 30 years for any one marine species. Despite these declines, Washington continues to support globally significant numbers of western grebes between late autumn and early spring. Up to 20 to 25 percent of the world population of western grebes (Kushlan et al. 2002) over-winter in the state. This suggests that Washington will play an important role in any conservation effort expended towards this species.

Relatively little is known about the breeding of western grebes or other grebe species in Washington. There is a relatively small number of western grebe breeding sites in Washington, centered in the Columbia Basin, especially Grant County (Wahl et al. 2005). The total breeding population is probably fewer than 1,500 adults, based on rough estimates for Grant County (J. Tabor pers. comm.).

The Western Washington University surveys also indicate a decline in red-throated and Pacific loons (Bowers et al. unpubl. data). Red-throated loons have declined by 73 percent and Pacific loons by 52 percent over the past 30 years.

Impacts to the Ecosystem

All loon and grebe species feed on young forage fish or other marine fish and invertebrates in greater Puget Sound. Since the distribution patterns during winter are different for each of these bird species, impacts on any particular prey population will depend on the timing and distribution of foraging birds. Although this has yet to be documented, declines in marine bird numbers are likely to have some impact on the forage fish or invertebrates they consume, on a local scale.

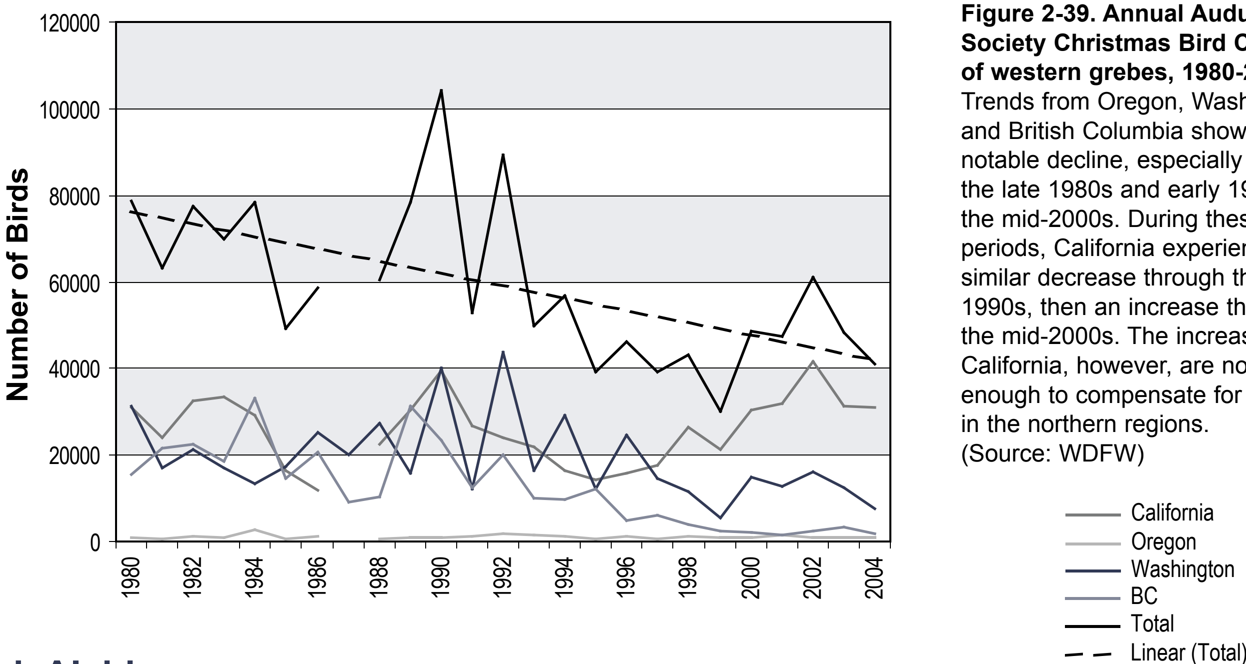


Figure 2-39. Annual Audubon Society Christmas Bird Counts of western grebes, 1980-2004. Trends from Oregon, Washington, and British Columbia show a notable decline, especially from the late 1980s and early 1990s to the mid-2000s. During these same periods, California experienced a similar decrease through the mid-1990s, then an increase through the mid-2000s. The increases in California, however, are not great enough to compensate for declines in the northern regions. (Source: WDFW)

d. Alcids

Pigeon guillemot (*Cepphus columba*), rhinoceros auklet (*Cerorhinca monocerata*), and marbled murrelet (*Brachyramphus marmoratus*) are the major species of alcids in Puget Sound. The Pacific coast population of marbled murrelets south of the Canadian border is listed as threatened by both USFWS and WDFW. The federal listing decision was based on the determination that the marbled murrelet was threatened from loss and modification of nesting habitat, primarily due to commercial timber harvesting of older forests, mortality associated with gillnet fisheries off the Washington coast, and mortality resulting from oil pollution.

Status and trends

The rhinoceros auklet is the most abundant breeding alcid in the inner marine waters of Washington; however, populations are concentrated at only two sites—Protection and Smith Islands. Recent publications (Wilson et al., 2005) confirm that breeding pairs of Rhinoceros auklets on these islands have declined from 17,000 pairs in 1975 to 12,000 pairs in 2000—a 30 percent decline.

Pigeon guillemot surveys completed in 2003 indicate that there are at least 471 colonies of pigeon guillemots in Puget Sound, with a total of approximately 16,000 breeding birds (Evenson et al. 2003). This makes this species the second most abundant alcid in Puget Sound during the breeding season. However, an absence of historical data on guillemot abundance makes it impossible to determine trends in population size. There are some conflicting reports from surveys of specific wintering areas (Nysewander et al. 2001, Bower et al. in prep.) that show both decreasing and increasing numbers for this species. The movement of pigeon guillemots in winter is not clear, and some evidence suggests that pigeon guillemots along the California and Oregon coasts move north to winter in Washington and British Columbia.

Marbled murrelets are non-colonial seabirds whose breeding distribution extends from the Aleutian Islands of Alaska to Santa Cruz, California. Estimated population size is about 859,000 in Alaska, 55,000 to 78,000 in British Columbia, and 17,000 to 27,000 in Washington, Oregon, and California (McShane et al. 2004). Six years of at-sea population monitoring now indicates that the

Has the marbled murrelet recovery plan made a difference?

Marbled murrelet populations have significantly declined in Washington over the past 25 years. Population modeling included in the marbled murrelet recovery plan (1997) suggested that populations were likely to be declining by four to seven percent per year. To monitor murrelet population trends more accurately, the Marbled Murrelet Effectiveness Monitoring Group (an entity made up of representatives from the U.S. Forest Service, USFWS, and state wildlife agencies) designed a coordinated at-sea monitoring program for the entire Pacific Ocean coast, south of the Canadian border. Results from the first six years of monitoring indicate that the population has been fairly stable during this period; however, variability in the results will require additional years of surveys to more accurately determine population trends (Miller et al. 2006, Raphael 2006).

Washington population is between 3,600 and 19,000 birds. From 2000 to 2005, annual population size estimates for three areas in Puget Sound ranged from 2,100 to 6,000 for the Strait, 1,300 to 2,200 for the San Juan Archipelago and northern Hood Canal, and 417 to 3,000 for southern Puget Sound. The highest densities of marbled murrelets in Washington are in the San Juan Islands, the Strait of Juan de Fuca, and along the northern outer coast (Cape Flattery to Point Grenville) (M.G. Raphael and S.F. Pearson unpubl. data).

Impacts to the Ecosystem

Alcids feed on forage fish and invertebrates, and declines in avian numbers may have an impact on abundance of species these birds normally consume. However, no studies have examined the effect of marine bird consumption on forage fish stocks.

e. Cormorants

The three cormorant species that frequent Puget Sound are the double-crested (*Phalacrocorax auritus*), pelagic (*Phalacrocorax pelagicus*), and Brandt's (*Phalacrocorax penicillatus*) cormorants. All three species breed on the Washington coast and are found throughout Puget Sound during winter. The double-crested and pelagic cormorants also breed and nest in portions of Puget Sound. Double-crested cormorants use both fresh and marine waters and, in some locations, travel between the two each day. In recent years, double-crested cormorants have been observed feeding on the increasing stocks of anchovy and other forage fish in southern Puget Sound.

The breeding success and breeding strategies of cormorants has been impacted by the recovery of Puget Sound bald eagle and peregrine falcon populations. Cormorant colonies are vulnerable to attacks and predation by both eagles and falcons, due to their nesting preference of open ground and cliffs. Both adult and immature eagles have been observed attacking cormorant nest sites and have likely disrupted or reduced nesting success for that year. Cormorants have developed several strategies in response to this predation, by selecting different nesting sites and varying the timing of egg-laying activities (Nysewander pers. comm.).

Status and Trends

The number of Pelagic cormorant nests in Puget Sound grew from 1,067 in the early 1980s (Speich and Wahl 1989) to 1,112 in 2003, a 4 percent increase. In addition to their customary Protection and Smith Islands sites, there were three large nesting colony sites observed in 2003: on Henry Island in the San Juan Archipelago, on Guemes Island in Skagit County, and at an urban site on the Warren Avenue bridge in Bremerton.

The number of Double-crested cormorant nests in Puget Sound grew from 550 during the early 1980s to 874 in 2003—a 59 percent increase. Populations are also increasing in the Great Lakes, the Mississippi River, and areas of the eastern U.S. The traditional colony sites in the San Juan Islands, including Protection and Smith islands, were used by lower numbers of breeders in 2003 than in previous years. However, a larger concentration of nests were found on the numerous, older pilings at the mouth of the Snohomish River near Everett in 2003. This represents 40 percent of the total number of cormorant nests in Puget Sound (Nysewander and Cyra, WDFW unpubl. data).

There has been both public and scientific interest expressed in determining whether cormorants that are currently roosting in Henderson and Totten Inlets in south Puget Sound might start using those locations to breed. To date, no nesting attempts have been reported in these areas.

Brandt's cormorants visit Puget Sound during winter but do not breed here. Their wintering populations in Puget Sound are unkown. However, USFWS has conducted a survey of Brandt's cormorants on the outer coast.

Impacts to the Ecosystem

Little is known of the impacts of cormorants on fish populations, although in recent years, double-crested cormorants have been observed feeding on the increasing stocks of anchovy and other forage fish in southern Puget Sound. Research is currently underway on the Columbia River to determine potential impacts of double-crested cormorants to salmon runs. Preliminary findings suggest that, while double-crested cormorants may consume portions of salmon runs, they also consume sizable numbers of salmonid predators, including the northern pike-minnow (Thompson pers. comm.). Future research will help determine how fish predation by cormorants positively or negatively affects salmon runs.

f. Caspian Terns

Caspian terns (*Sterna caspia*) are uncommon in Puget Sound, although nesting colonies have been documented in recent decades. A sizable colony resided near Everett until the U.S. Navy base was built there in the early 1990s. Until it was displaced in 2002, another colony nested near the ASARCO plant on the shoreline of Tacoma's Commencement Bay. Smaller groups of Caspian terns have been seen each summer in various locations around Puget Sound but they are not monitored. Caspian terns forage fairly high over salt water or fresh water, often plunge-diving for small fish.

Status and Trends

USFWS conducted a study in 2004 and 2005 to monitor nesting Caspian terns on the Dungeness Spit within the Dungeness National Wildlife Refuge. This nesting colony was first observed on the refuge in 2003. In 2004, the colony consisted of 233 to 293 nesting pairs and in 2005, the colony more than doubled to 680 nesting pairs. There is speculation that most of the birds now nesting at this new colony site are from the displaced colony that nested in Commencement Bay from 1999 through 2002.

Impacts to the Ecosystem

Implant tags from young salmonids found at the colony sites reveal that Caspian terns prey on young salmon (smolts). While debate continues on the relative importance of Caspian tern predation on salmonid smolts, an attempt was made to move tern colony sites along the Columbia River away from concentration areas where young salmonids are most vulnerable. This relocation of the colony site was successful, but there is another effort underway to move the colony even further away.

g. Gulls

Approximately 10 species of gulls are found in Puget Sound. Only two of these species, the glaucous-winged gull (*Larus glaucescens*) and the western gull (*Larus occidentalis*), breed in Washington's marine waters. Both species breed (and interbreed) on Washington's outer coast. The glaucous-winged gull also breeds in the inland marine waters of Puget Sound. Of these two gull species, the glaucous-winged gull is the most common.

The most common of the gull species that use Puget Sound habitats after breeding elsewhere include the Heermann's gull (*Heermanni philadelphia*), which breeds in Mexico, the Bonaparte's (*Larus philadelphia*), Thayers's (*Larus thayeri*), and Herring gulls (*Larus argentatus*), which breed in the north, and the Ring-billed (*Larus delawarensis*) and California gulls (*Larus californicus*), which breed inland. Some, including Heermann's gull, come to Washington's marine waters during the summer and fall, in between breeding seasons. Others tend to visit Washington during winter months.

Status and Trends

Gull populations grew during the early 1900s because of increased human-generated food opportunities (such as landfills) and declines in egg and feather harvesting. However, the recovery of bald eagle and peregrine falcon populations during the past 25 years coupled with the removal and/or covering of landfills and other human-generated food sources has resulted in a decrease in gull populations at traditional marine colony sites. Declining forage fish stocks near colony sites may have also played roles in these declines.

In the 1980s, there were an estimated 8,851 glaucous-winged gulls breeding on 36 sites in the vicinity of the San Juan Islands (Speich and Wahl 1989). PSAMP re-visited the same 36 sites in 2001 and documented 3,568 breeding birds, a 60 percent decrease (Nysewander unpubl. data). Most of the individual nesting sites appear to have declined, with the exception of two islands in the Cattle Pass area, where the population either remained the same (Hall Island) or increased (Goose Island). This decline may be accounted for through redistribution to larger colonies, such as Smith or Protection Islands; however, surveys of gull nesting efforts on Protection Island in 2005 revealed large declines associated with factors such as the increase in numbers of eagles frequenting the colony (Joe Galusha pers. comm.). Nevertheless, it is possible that gulls may be redistributing to urban and industrial habitats along the Columbia River (J. Galusha pers. comm., R. Woodruff pers. comm.). However, these urban and industrial areas have not yet been surveyed. USFWS's Migratory Bird Program in Portland, Oregon is planning some coordinated surveys in the next few years to look at all of these habitats, including urban, industrial, and military locations.

WWU scientists who replicated the 1978-1979 MESA surveys from ferry or land-based observations during September to May each year in 2003-2005 also reported declining trends for Heermann's (89 percent), Bonaparte's (68 percent), and glaucous-winged gulls (14 percent) (Bowers et al. unpubl. data).

Impacts to the Ecosystem

It was once thought that the increasing gull populations might have considerable negative impacts through predation on other marine bird species nesting nearby. However, since gull populations are decreasing, they don't appear to be having the same impact on other birds.

i. High Arctic Black Brant

Wintering flocks of the Western high arctic black brant (*Branta bernicla*) can be seen from late November through May in Padilla, Samish, and Fidalgo bays of Skagit County in Puget Sound. This unique stock of brant breeds in the Parry Islands of the Northwest Territories of Canada. Other wintering flocks of brant that visit Puget Sound breed in other arctic areas of Canada and Alaska. Areas used by brant in Puget Sound include Dungeness Spit (approximately 1,000 birds), and Hood Canal (approximately 500 birds), although smaller flocks occur in isolated areas in southern Puget Sound.

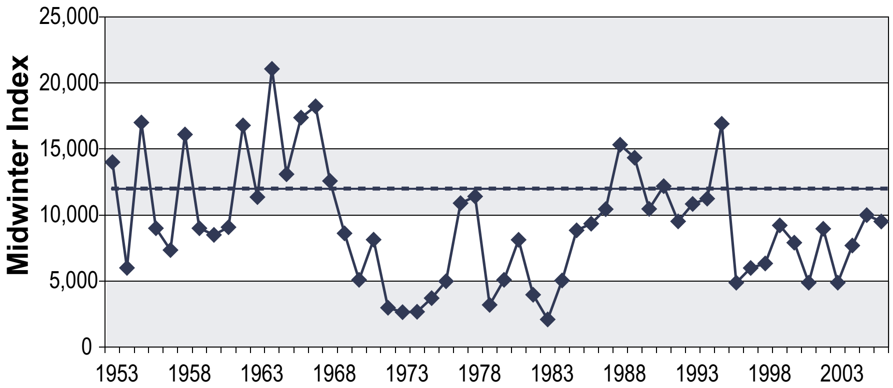


Figure 2-40. Western high arctic black brant populations in Puget Sound. The midwinter index is calculated from January aerial surveys of Skagit County. The target for brant populations in Puget Sound is 12,000 (dotted line). (Source: WDFW)

Status and Trends

Numbers of brant have declined since the 1960s, when the entire brant population was approximately 13,330 birds. Since 1970, the population has varied from a low of 2,105 in 1983 to a peak of 16,900 in 1995, with an average of 7,283 between 2001 and 2005. The midwinter index shown (Figure 2-40) is derived from January aerial surveys of Skagit County.

Impacts to the Ecosystem

Brant are an integral part of the north Puget Sound ecosystem. They are dependent on eelgrass beds and have been documented to use herring spawn for feeding during spring migration. In addition, they provide food for primary predators including bald eagles.

j. Great Blue Heron

The great blue heron (*Ardea herodias*) is found across most of North America. In Washington, two subspecies occur (Payne 1979, Butler 1997). The coastal subspecies, commonly referred to as the Pacific great blue heron, is distributed along the Pacific Ocean coast from Washington to Alaska. This heron is non-migratory and marine-oriented, nesting close to tidal shorelines and foraging within estuaries and marine waters of Puget Sound. Primary threats to the heron population include bald eagle depredation, habitat loss, and human disturbance (Norman et al. 1989, Butler 1997, Butler and Vennesland 2000).

The majority of herons is concentrated in north Puget Sound and is associated with extensive eelgrass beds near breeding colonies. Areas of high heron numbers include, Drayton Harbor, Port Susan, and Lummi, Portage, Samish, Padilla, and Skagit Bays.

Status and Trends

Population trends for Pacific great blue heron are unclear, because historic data on colony size were collected using non-standardized methods. Today, an estimated 6,000 to 12,000 Pacific great blue herons occur in south coastal British Columbia and western Washington. This rough estimate is based on populations in colonies, which can be difficult to locate. In addition, herons move frequently and often abandon colonies, particularly smaller ones. Conducting systematic counts of herons on their feeding grounds may prove valuable to monitor changes in population numbers; the assumption is that locations of colonies may shift in the uplands, but the major foraging areas remain constant.

In 2003 and 2004, biologists with WDFW began a pilot study at nine heron colonies, distributed from south to north Puget Sound and Hood Canal to evaluate the use of foraging ground counts of herons as an index for change in adult breeding heron populations in these areas. For this study, researchers examined the timing of breeding, surveyed forage areas by air and ground, and documented changes in heron numbers on tidal foraging areas.

Breeding timing was highly synchronous among heron colonies in Puget Sound and Hood Canal in 2004. In general, herons returned to colonies by mid-March, with egg-laying beginning by late March and peaking by early April. Eggs began hatching in mid- to late April, with a peak in late April and early May, and most chicks fledged by late June or early July. On days of maximum annual spring tides in early June, numbers of herons increased on tidal foraging areas as the tide ebbed. Numbers of herons typically peaked around the time of peak minus tides and showed variable rates of decline in numbers on flooding tides. During minus tides in mid-May 2004, a total of 3,069 great blue herons was counted along mainland shorelines from the Fraser River estuary through Puget Sound and Hood Canal. During the maximum spring tides of early June 2003, 3,846 herons were counted, compared to 4,262 during this same period in 2004. In mid-June 2004, 4,546 herons were counted during minus tides.

A small number of great blue heron colonies are known along the outer coast. In 2005, WDFW biologists conducted an aerial survey of great blue herons from the entrance of the Columbia River north along the outer coast, including Willapa Bay and Grays Harbor, north to Cape Flattery and east to Port Townsend. A total of 1,227 great blue herons were counted, with the majority of herons occurring in Willapa Bay and Grays Harbor.

k. Bald Eagle

Bald eagles (*Haliaeetus leucocephalus*) are currently listed as threatened under the ESA. U.S. Fish and Wildlife Service proposed to change this status in 1999; however, the change was not completed. In June 2004, the process of delisting the bald eagle was proposed again, and, in 2005, state and federal agencies conducted a pilot study to guide development of a national monitoring plan. In Washington, the northern subspecies is the common bald eagle.

The average home range of a bald eagle in Puget Sound is 2.6 square miles (673 hectares) (Watson and Pierce 1998). In Clallam and San Juan counties, each active nest encompasses approximately four to 5.6 miles (1,450 hectares) of shoreline (Stinson et al. 2001). The winter ranges are larger and more varied than breeding home ranges (Watson and Pierce 2001); however, the post-breeding dispersal of the bald eagle is partially known. Many of Washington's breeding eagles move northward to coastal British Columbia and Alaska after nesting to feed during the late summer and fall salmon runs (Stinson et al. 2001), although some birds remain in Washington after breeding. Regular winter concentrations on the major rivers (such as those seen annually over 24 winters on the Skagit River), are primarily composed of northern birds, migrating south from Alaska and Canada to feed on salmon runs (Watson and Pierce, 2001).

Foraging areas for this species are considered the most essential component of the habitat used by bald eagles (Stalmaster 1987), followed by the presence of large nesting trees (Watson and Pierce 1998). The nesting pairs continually work to maintain their nests which may be functional for 5 and 20 years (Stinson et al. 2001). Eagle pairs will also usually build alternative nests within the nesting territory. Because of the need for alternate nests and protection of nest trees from wind throw, mature forest stands with several large trees are needed to provide support over a long period. Foraging habitats must include consistent supplies of food and minimal human disturbance (Stinson et al. 2001) and be optimally located in open areas with nearby nesting, roosting, and perching trees (Stalmaster 1987). During the summer on Washington's outer coast, bald eagles feed opportunistically on intertidal invertebrates and wildlife carcasses. However, reductions in the bald eagle's principal prey—dying salmon in Puget Sound's rivers—are a primary concern for year-round resident eagles. Habitat degradation, non-native species introductions, and loss of prey resources may also affect the annual survival and reproductive success of the bald eagle (Spencer et al. 1991, in White 1994). Currently, low salmon escapement in the Skagit River watershed is a limiting factor for wintering eagle populations (Dunwiddie and Kuntz 2001, in Stinson et al. 2001).

Protecting Bald Eagles

Bald eagle habitat is protected under the Bald Eagle Protection Law of 1984, which requires the establishment and enforcement of buffer zones around bald eagle nests and roost sites. A subsequent Bald Eagle Protection Rule, the primary focus of which is to protect habitat via site management plans, was established by a group of stakeholders and adopted by the Washington State Wildlife Commission in 1986.

Status and Trends

WDFW has been monitoring bald eagle abundance in Washington for over 25 years. Surveys and individual site visits are limited primarily to areas of high eagle density in Puget Sound, including the Strait of Juan de Fuca and San Juan Islands, as well as sites along the outer coast (D. Stinson pers. comm.). The historical population of this species was estimated at 6,500 birds (based on carrying capacity), but is currently estimated at 4,400 birds statewide (Stinson et al. 2001). This reduction in population is likely to be a result of human encroachment into critical nesting, roosting, and foraging habitats, exposure to biocides and other contaminants, and the reduction of food resources. Many bald eagles have become urbanized, utilizing alternative, human-built structures and environments to maintain local populations.

In 2005, a total of 503 territories, or 1,014 nests, were surveyed within the Puget Sound Bald Eagle Recovery Zone (Figure 2-41 and Figure 2-42) representing an increase over the past 10 years. Of the territories visited, 354 were confirmed occupied, with breeding pairs present at 94 percent of the occupied sites. Breeding activity is confirmed by the presence of eggs or shells in or around the nest or observations of adults incubating eggs or brooding chicks.

Bald eagle surveys in Puget Sound involve checking for new and previously utilized nests and documenting whether the nests are occupied. This is due in part to increased survey effort, but also indicates an increase in breeding population. The population increase is best reflected by comparing years with similar survey efforts. Specifically, WDFW conducted comprehensive statewide surveys in 2001 and 2005 and found an increase in nesting pairs—that is, more new and occupied nests were located in 2005 than in 2001.

Impacts to Ecosystem

Bald eagles are both predators and scavengers and play important roles in nutrient cycling in Puget Sound's shorelines and watersheds.

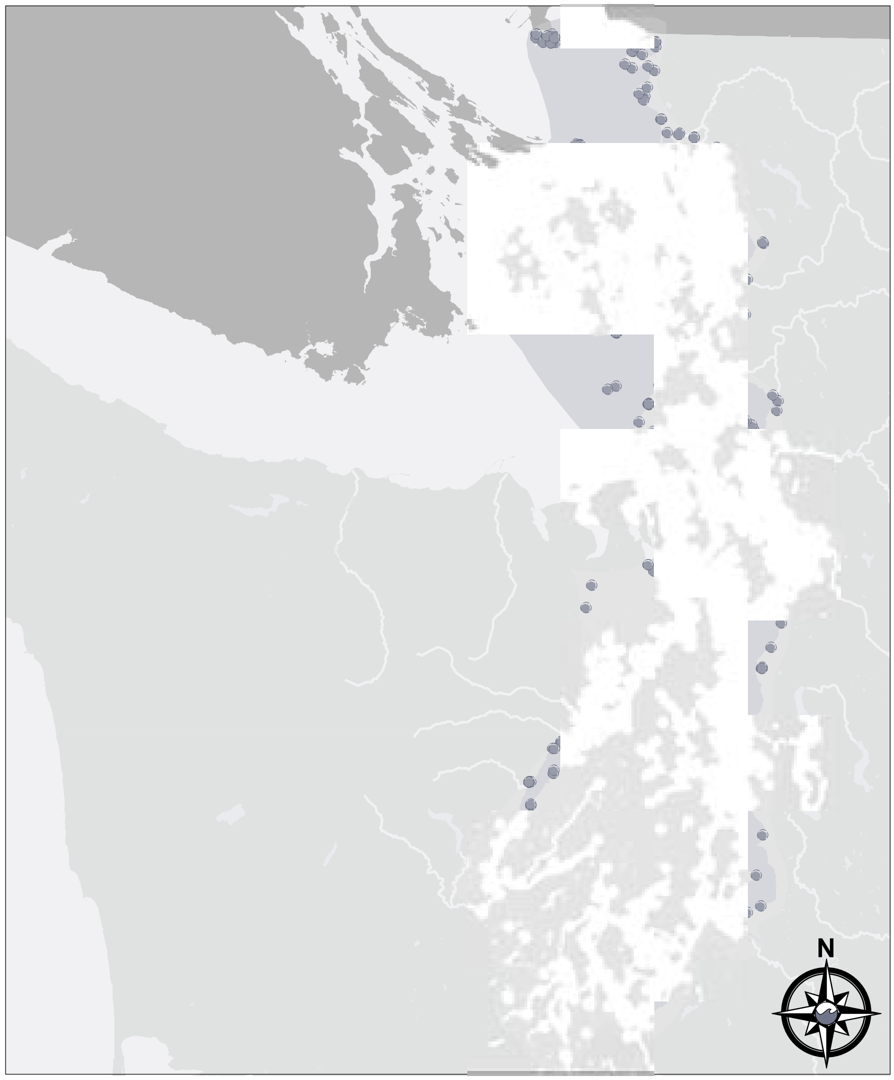


Figure 2-41. Locations of known bald eagle nests in Puget Sound in the Bald Eagle Recovery Zone (highlighted area) as of May 2006. The number of new and existing territories has increased within the past 10 years. (Source: WDFW)

Nest Location

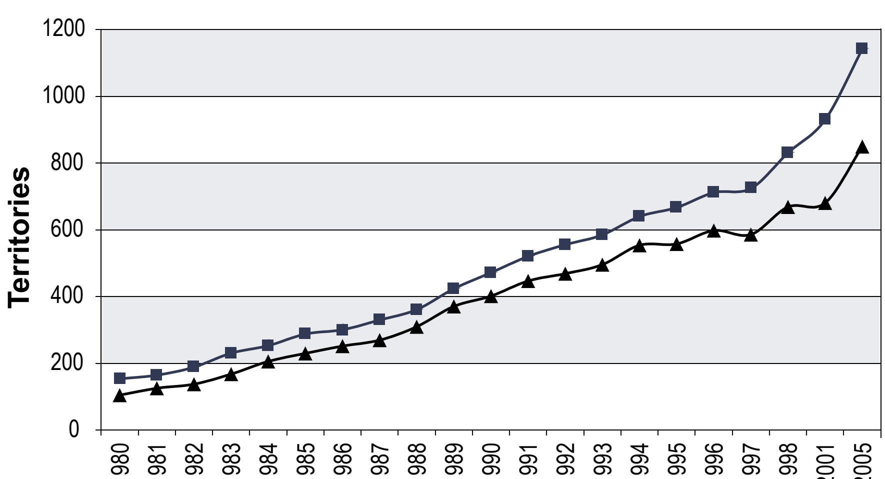


Figure 2-42. Eagle surveys in the Puget Sound Recovery Zone 1980-2005. The number of new and existing bald eagle territories in the Puget Sound Bald Eagle Recovery Zone. The number of discovered and checked sites has increased within the past 10 years, in part because of increased survey efforts and an increase in the breeding population. There were more nesting pairs in 2005 (new and occupied nests) compared to 2001. (Source: WDFW)

■ Territories checked

▲ Territories occupied

9. Marine Mammals

a. Sea Otters

Sea otters (*Enhydra lutris kenyoni*) were common along Washington's Pacific Ocean coast until they were extirpated during the fur trade early in the 20th century. The current population off the Washington coast was reestablished by translocation from Alaska's Amchitka Island in 1969 and 1970, when a total of 59 otters was released.

The Washington sea otter population is subject to protection under the federal Marine Mammal Protection Act, as well as listed as endangered by the state of Washington. In recent years, anomalous strandings of sea otters on the ocean coast have led to concern that sea otters may be ingesting contaminated prey and suffering increased mortality rates as a result of immunosuppression from contaminants or *Morbillivirus*, which has recently been detected in this population. USFWS, along with its partners, embarked on a study to address the questions surrounding the contaminant and mortality issues facing the Washington sea otter population.

Status and Trends

In the latest census, conducted in July 2005, 814 sea otters were counted—a 10 percent increase from 2004. Overall, there has been an average rate of increase of 8.2 percent since 1989, and it would appear that the sea otter population, which currently ranges from Kalaloch to the western Strait of Juan de Fuca, is still in a positive growth phase.

In 2001 and 2002, a survey for pathogen exposure in sea otters was conducted by WDFW. Thirty animals were captured and tested for a variety of parameters. Whole blood was collected to determine exposure to a variety of pathogens, including *Morbillivirus*, *brucella*, *leptospirosis*, and *toxoplasmosis*. Samples from live otters never yielded positive tests for brucella or calicivirus, but testing for *neospora* (50 percent), *sarcocystis* (29 percent), and *leptospirosis* (3 percent) was positive in some animals. The most interesting findings were the toxoplasmosis and *Morbillivirus* titers. Sixty percent of the live animals tested positive for toxoplasmosis, while 80 percent tested positive to *Morbillivirus*. Generally, the *Morbillivirus* results were higher for the canine distemper strain of the virus; however in a few instances, the phocine distemper virus results were equivalent or higher for individual animals. This was the first positive finding of *Morbillivirus* in sea otters.

Impacts to the Ecosystem

Analyses of samples from live captured sea otters off the Washington coast indicate relatively low exposure to contaminants but suggest evidence of pathogen exposure. Infectious disease presents a potential risk to Washington sea otters, particularly because of their relatively small population size and limited distribution. Despite these significant findings in live otters, cause of death of stranded sea otters has not generally been attributable to either *Morbillivirus* or *Toxoplasma*, and many of the sea otters that tested positive for these pathogens were tracked following this investigation and found to be alive and presumably well. The high prevalence of antibodies to *Morbilliviruses* in the sampled animals suggests that the Washington sea otter population is fairly well protected against a widespread *Morbillivirus* outbreak. Individual deaths may occur, but a population-threatening die-off from this disease is unlikely while population immunity remains high.

Washington's sea otter population continues to grow, with an estimated 800 animals currently inhabiting Washington waters. However, the population remains well under historic levels, and the population has not yet reached its carrying capacity. As such, is still considered at high risk to catastrophic events such as oil spills.

b. Harbor Seals

The harbor seal (*Phoca vitulina*) is a small, stocky, eared seal found throughout the temperate and Arctic waters of the northern hemisphere and has the widest distribution of any pinniped. In the Pacific Ocean, harbor seals inhabit coastal and estuarine waters from Baja California to Japan. Harbor seals are generally considered non-migratory, breeding and feeding in the same general area throughout the year. Within their residing areas, their activity may be driven by daily and seasonal variation in tides, weather, prey availability, and reproduction.

Harbor seals are the most common, widely distributed pinniped in nearshore waters of Washington. They use hundreds of sites to rest or haul out, including intertidal sand bars and mudflats in estuaries, intertidal rocks and reefs, islands, logbooms, docks, floats, and sandy, cobble, and rocky beaches. Group sizes typically range from a dozen or fewer animals on small intertidal rocks or reefs to several thousand animals hauled out seasonally in coastal estuaries. Males and females are similar in size (to 250 lbs) and coloration. Pelage patterns are typically a light base with dark spots, although the pelage of some individuals is reversed in coloration, with dark base and light spots.

Harbor seals have an annual reproductive cycle with the birth season typically lasting up to two months. Females produce one pup per year, beginning at age four or five. Pups are precocious at birth, capable of swimming and following their mothers into the water immediately after birth. Pups typically remain with their mothers until weaning at four to six weeks of age. Harbor seal pupping seasons vary by geographic area in Washington, with pups born along the ocean coast from mid-April through June and in the inland waters from June through August. Hood Canal is somewhat of an anomaly, with births and nursing pups recorded from July to January.

Status and Trends

During the first half of the 20th century, numbers of harbor seals (as well as sea lions) were severely reduced in Washington by a state-financed bounty and control programs that considered seals and sea lions to be salmon predators in direct competition with commercial and sport fishermen. After bounties and control programs ended, and federal protection was established with passage of the Marine Mammal Protection Act in 1972, harbor seal populations in Northwest waters recovered and are now at or near historic levels. Today, Washington's harbor seal population numbers are in excess of 30,000 animals, with 16,000 on the outer coast waters and 14,000 in inland waters.

Impact to the Ecosystem

As a long-lived, non-migratory, high-trophic-level predator in Puget Sound, harbor seals are excellent indicators of contaminants in the marine environment. With a diet consisting of a variety of prey, including Puget Sound herring, anchovy, Pacific hake, salmonids, cod, flatfish, pricklebacks, greenlings, sculpins, lamprey, and smelts, harbor seals bioaccummulate persistant toxins (PBTs) from these prey via dietary intake. Spatial studies of various persistant bioaccumulative toxins in harbor seal blubber have shown that Puget Sound animals are seven times more contaminated with PBTs than those inhabiting the Strait of Georgia (see Chapter 4, Section 3c). Recent studies have also profiled the rapid emergence of flame retardants, or polybrominated diphenylethers (PBDEs) in marine food webs by looking at concentrations in harbor seals as well (See Section 3c in Chapter 4). Harbor seals continue to provide a valuable tool for looking at contaminants in the marine food web and an overall indicator of the health of Northwest waters.

c. California Sea Lions

California sea lions (*Zalophus californianus*) are the most frequently sighted otariid, or eared seal, found in nearshore coastal waters of Washington. Animals present in Washington waters typically include all age classes of males ranging in size from 100 to 1,000 lbs. Females with pups and juveniles typically remain to feed in waters near their breeding rookeries off the California coast. (Note: In recent years, a few females have been reported in Northwest waters but are still considered rare outside of California waters.) Coloration of males is usually a dark or chocolate brown. A high forehead, or sagittal crest of the male is distinctive. In older males, the hair on top of the head becomes blond in color. Vocalizations can be described as barking. Male California sea lions migrate northward in search of food during late summer and early fall as a result of dispersal from their breeding rookeries in the Channel Islands off California. This dispersal results in animals moving into nearshore waters off Oregon, Washington, and British Columbia. These animals remain in Northwest waters until late spring, when the majority head south to their breeding rookeries off California.

California sea lions use a variety of haul-out sites, such as offshore rocks and islands, jetties, logbooms, navigation buoys, and marina docks. In Washington, this species uses haul-out sites along the Olympic Peninsula coast (Carroll Island, Cape Alava, and Tatoosh Island), in the Strait of Juan de Fuca (Race Rocks) and in Puget Sound (logbooms near Everett and most navigation buoys). This species is also frequently seen throughout Puget Sound, resting alone or rafted together in groups with flippers in the air.

Status and Trends

Population estimates for California sea lions in U.S. waters are based on multiplying pup production by the fraction of newborn pups in the population. Using this method, it is estimated that 237,000 to 244,000 animals inhabited U.S. waters in 2003. Based on an analysis of pup counts from 1983 to 2003, the California sea lion population has been increasing by five to six percent annually. The largest California sea lion aggregations in Washington have occurred near Everett in Puget Sound, where numbers increased from 108 in 1979 to a maximum of 1,234 in the spring of 1995. Since 1995, a shift in distribution from inland waters to the outer coast has been observed, with 4,000 to 5,000 animals observed near Cape Alava on the Olympic Peninsula coast in the fall. An additional 1,000 to 1,500 California sea lions are present seasonally in British Columbia.

Impacts to the Ecosystem

California sea lions are opportunistic feeders that prey on a wide variety of fish and invertebrates. Their diet is diverse and varies seasonally by location. Some of the common prey in Northwest waters includes herring, Pacific hake, salmon, steelhead, anchovy, sardines, smelts, lamprey, dogfish, squid, and octopus. California sea lions tend to congregate at the mouths of rivers or estuaries, where prey is abundant, and are known to feed on seasonal concentrations of smelt, salmon, and steelhead entering these rivers and estuaries. Movement and re-distribution of California sea lion concentrations in Northwest waters have been correlated with spawning aggregations of various prey, including Pacific whiting, herring, and salmonids, and indicate the ability of California sea lions to find locally abundant concentrations of these species. Predation on salmonids by this species has been identified as an area of concern at the Hiram M. Chittenden Locks in Ballard, Willamette Falls, Bonneville

Dam, and other locations. Salmon is a seasonally important prey of California sea lions, which are considered to compete with orcas for salmon.

d. Steller Sea Lions

Steller (or northern) sea lions (*Eumetopias jubatus*) are the largest otariid in Northwest waters and are present year-round. This species ranges along the North Pacific Ocean coastline, from California to Japan. For management purposes, the Steller sea lion population is divided into two distinct segments or stocks, designated as the Eastern U.S. Stock (distributed from California to Cape Suckling, Alaska) and Western U.S. Stock (distributed from Cape Suckling, Alaska, to Hokkaido, Japan). Steller sea lions in Washington are considered part of the Eastern U.S. Stock. Both sexes occur in Washington waters, with adult males (to 2,200 lbs or 1,000 kg) being considerably larger than females (to 700 lbs or 317 kg). Coloration varies from tawny through yellowish brown to dark brown. Vocalizations from adults can be described as deep growling sounds.

Status and Trends

Breeding rookeries are located along the California, Oregon, British Columbia, and Alaska coasts. With the exception of rookeries in California, the Western U.S. population has increased at over three percent annually since the 1970s and is currently estimated at over 31,000 animals. Four main haul-out areas are located along the outer Washington coast near Split Rock, Carroll Island, Cape Alava, and Tatoosh Island. Peak abundances occur during fall and winter months, with 1,000 to 1,500 animals along the outer Washington coast. These animals are assumed to be immature animals and nonbreeding adults associated with rookeries from other areas. At these same seasons and into the spring, 800 to 1,000 animals move through the Strait of Juan de Fuca and into the Strait of Georgia to feed on herring (that spawn north of Nanaimo) and Pacific hake. Relatively small numbers use haul-out areas in the San Juan Islands at Whale Rock, Bird Rocks, Peapod Rocks, Speiden Island, and Sucia Island. Aerial surveys conducted by the WDFW since the early 1990s show the Washington Steller sea lion population increasing at a rate of 9.6 percent annually.

Impacts to the Ecosystem

Steller sea lions are an opportunistic predator that feeds primarily on fish, octopus and squid, with prey varying by season, area, and water depth. Their diet consists of herring, hake, salmon, cod, lamprey, rockfish, flatfish, skates, squid, and octopus. Salmon are seasonally important and range from six to 33 percent of the animals' diet. Steller sea lions compete with other pinnipeds and with orcas for salmon returning to Washington rivers and streams.

e. Porpoises

Harbor porpoise (*Phocoena phocoena*) and Dall's (*Phocoenoides dalli*) porpoise are members of the Phocoenidae family, sometimes called true porpoises. They are the most common small cetacean in the greater Puget Sound area (Osborne et al 1988, Calambokidis and Baird 1994). Both are fairly small and generally less than 2 meters (6-feet long). Dall's porpoise often approach boats to bow-ride and are capable of high speeds that allow them to streak through the water, creating characteristic rooster tails. Their dramatic black-and-white coloration confuses many people into thinking they are baby orcas. Harbor porpoise tend to avoid boats and are much less distinct in coloration and behavior. Their small, nondescript size makes them easy to overlook in all but the calmest of conditions.

Dall's porpoise occur broadly in the northern North Pacific in inshore, coastal, and pelagic waters. Harbor porpoise utilize primarily coastal and inland waters (generally less than 328 feet or 100 m deep) and occur in Northern Hemisphere temperate and Arctic waters. Both species can occur in almost all Puget Sound waters, although Dall's porpoise are currently more common than harbor porpoise in Puget Sound proper. Information from contaminant ratios and genetics suggest harbor porpoise form fairly distinct, localized populations (Calambokidis and Barlow 1991, Chivers et al. 2002), raising concern about the impact of localized causes of mortality.

Status and Trends

Harbor porpoise were considered the most common small cetacean in Puget Sound in early accounts from the 1940s. Sightings within Puget Sound have been rare in the last 30 years. The reason for their virtual disappearance from Puget Sound is not known but is consistent with declines in other areas and is likely the result of some combination of factors, including high vessel traffic, entanglement, and contaminants. There have been some indications of increased sightings of harbor porpoise within Puget Sound in recent years.

Concern over harbor porpoise status and, specifically, the impact of mortality from entanglement in fishing nets has prompted the National Marine Mammal Laboratory, in collaboration with Cascadia Research, to conduct periodic aerial surveys to estimate harbor porpoise abundance. Surveys were most recently conducted off Oregon, Washington, and southern British Columbia, including the inside waters, in 2002 and 2003. These provided an estimate of 10,682 harbor porpoise in Washington's inside waters and an estimate of 37,745 for waters along the Pacific Ocean coast of Oregon (north of Cape Blanco) and Washington (J. Laake et al. Unpubl. data). Estimates in outer coastal waters were similar to the previous survey in 1996 and 1997, while those in inside waters were higher than had been previously documented (Laake et al. 1998, Calambokidis et al. 1997).

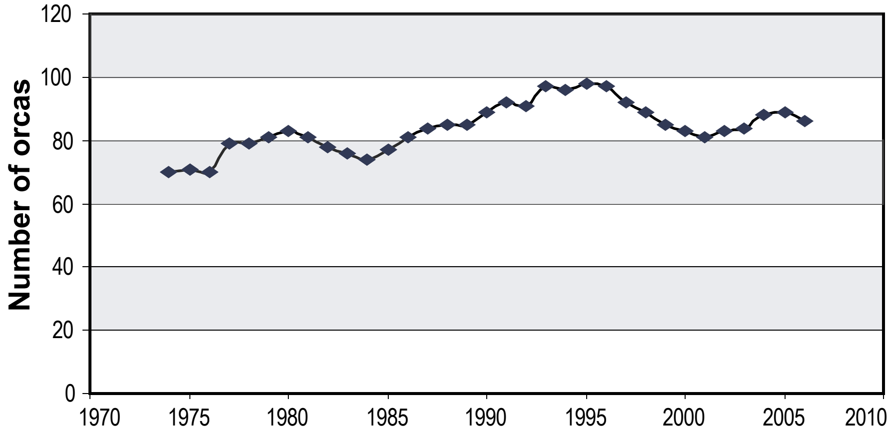
Impacts to the Ecosystem

Harbor porpoise and Dall's porpoise are both caught in nets incidental to commercial fishing activities. They generally consume small fish and are not competitors for commercially valuable fish. Both are occasional prey of transient, mammal-eating orcas. They are also known to occasionally interbreed and hybrids between the two species have been documented frequently in the San Juan Islands (Willis et al. 2004).

f. Orcas

Orcas (*Orcinus orca*), also known as killer whales, are distributed throughout the marine waters of Washington. Three main populations are referred to as southern residents, transients, and the offshore population (Wiles 2004). These populations rarely interact and do not interbreed, despite having largely similar year-round geographic ranges extending into British Columbia and other areas along the west coast of North America. Southern resident and transient orcas are the only populations that regularly enter the state's coastal waters, whereas offshore orcas mainly inhabit the open ocean off the outer coast. The southern residents are thought to feed almost exclusively on salmon, especially chinook and chum. They occur in small, highly stable social units known as matrilines, in which all individuals are maternally related. Pods are larger social groups comprised of several matrilines and typically hold about 10 to 60 animals. In contrast, transient orcas feed primarily on harbor seals and other marine mammals. They also travel in small matrilineal groups, which typically contain one to six animals, but these

Figure 2-43. Population size and trend of southern resident orcas, 1974-2006. Currently the population consists of 86 individuals. Between 1974 and 1995, the population increased from 70 to 98 whales, but this gain was followed by a rapid net loss of 17 animals, or 17 percent of the population, between 1996 and 2001. (Source: Center for Whale Research)



associations are generally looser than among resident groups. Few details are known about the biology of offshore orcas, but these are typically larger groups and the members are believed to be mainly fish-eaters.

Status and Trends

The southern resident population consists of three pods (identified as J, K, and L pods), which contain the majority of orcas found in Washington. The three pods are usually present in the Georgia Basin and Puget Sound waters from late spring to fall. The population travels more extensively during other times of the year to sites as far north as northern British Columbia and as far south as central California. Data on earliest southern resident population trends are from 1960, when roughly 80 whales were present; these numbers may not reflect true historic population sizes as whales may have been depleted by indiscriminant shooting by fishermen. The population's recovery was impaired during the early- and mid-1960s and 1970s, when live captures for aquaria removed or killed at least 47 individuals.

The southern resident population has been closely monitored since 1974, with exact numbers of animals and other demographic details learned through annual photo-identification surveys. Between 1974 and 1995, the population increased from 70 to 98 whales but this gain was followed by a rapid net loss of 17 animals, or 17 percent of the population, from 1996 to 2001 (Figure 2-43). J and K pods generally maintained their numbers during the decline, but L pod, which comprises about half of the southern resident population, sharply declined. L pod's decline involved both increased mortality of members and lowered birth rates. Southern resident numbers have again been growing since 2001 and are currently at 90 individuals, although reports at press time indicated three orcas may have died of starvation in the fall of 2006. Population trends of transient and offshore orcas are not known, because of their greater mobility and more sporadic occurrences, which makes it difficult for researchers to maintain detailed photographic records of both groups.

Orcas in Washington face several main potential threats. These include: large historic declines in salmon for the southern residents; declining health and reproductive capacity due to high levels of pollutants—PCBs, DDTs, PBDEs, and, perhaps, other chemicals; increased noise and disturbance from whale-watching boats and other vessels; and major oil spills.

Impacts to the Ecosystem

Orcas are top-level predators. Their impacts on salmon populations are unknown but are probably fairly minimal under most circumstances. Effects on pinniped populations are also likely to be minor, except where whales remain for long periods within localized areas. For example, groups of transients are thought to have substantially reduced the harbor seal population in Hood Canal during multi-month stays in 2003 and 2005.

Human Health Consequences

Transient and southern resident orcas are among the most highly contaminated marine mammals in the world—a condition that results from their position as apex predators. This reflects a continuing presence of worrisome levels of certain pollutants in the greater Puget Sound area and the region's other marine ecosystems. Washington's orcas and humans share certain foods, especially salmon; thus, there is concern that humans may be consuming unhealthy levels of the same pollutants. These problems signal a greater need for stronger anti-pollution regulations and enforcement, plus additional cleanup activities.

g. Minke Whales

The first minke whale (*Balaenoptera acutoraostrata*) described in Puget Sound was a 27-foot (8m) female stranded in Admiralty Inlet in 1874 (Scammon 1874). Live minke whales have more recently been observed in various parts of Puget Sound and the Straight of Juan de Fuca. The International Whaling Commission identified three North Pacific minke whale stocks: two in the western Pacific and a third, the remainder stock, consisting of whales in the eastern Pacific (Donovan 1991). NMFS further divided the remainder stock into Alaskan, Hawaiian, and the California-Oregon-Washington (CA-OR-WA) stocks, which was partially based on research showing that the coastal minke whale stock consisted of small, regional populations. Individual minke whales have sited multiple times within and between years in the 1980s, with no movement observed between Washington, British Columbia, and California populations. Sightings occurred year-round (Scammon 1874, Everitt et al. 1979), although the greatest research effort was made during summer months (Dorsey et al. 1990).

The Makah Indians of Cape Flattery occasionally hunted the minke whale (Scammon 1874; Scheffer and Slipp, 1948). Currently, the whales are the subjects of whale-watchers in the Straight of Juan de Fuca.

Status and Trends

The current size estimate for the CA-OR-WA minke whale population is 1,015 individuals, with a minimum population size estimate of 585 individuals. Net fisheries and ship-strike interactions are a concern. The stock has never been hunted commercially, so the reason for the small population size is unknown. Three primary feeding areas have been discovered for minke whales. These are Waldron Island, the San Juan Channel, and the Strait of Juan de Fuca. Individuals in these areas often use distinctive feeding behaviors associated with the kinds of available prey (Dorsey 1983, Dorsey et al. 1990, Hoelzel et al. 1989). Hoelzel et al. (1989) identified prey as herring and sand lance. In the 1980s, the Waldron Island area was consistently occupied by at least five individuals during the summer months. Although monitoring efforts have been reduced since the 1980s in this area, only a few scattered sightings have been reported. More sightings were reported in the Strait of Juan de Fuca. In 2003, minke whales were again seen north of San Juan Island.

Impacts to the Ecosystem

The impact of minke whales on the Puget Sound ecosystem is unclear, but under investigation. About 17 individuals were identified per year in the early 1980s (Dorsey et al. 1990). They feed in the area and consume an unknown quantity of herring and sand lance (Hoelzel et al. 1989). They are most frequently seen over submarine banks and in areas of vigorous tidal activity—areas with high concentrations of prey.

h. Humpback Whales

Humpback whales (*Megaptera novaeangliae*) occur in all oceans of the world. They are listed as endangered, due to the decimation of their populations from commercial whaling, which continued up to 1966. Whaling stations operated near Puget Sound in the 1900s, including Bay City (Grays Harbor) and several locations on Vancouver Island. Humpback whales were historically fairly common in the inside waters of Washington and British Columbia. An intensive but short period of whaling, targeting these whales in inside waters, appeared to eliminate this population.

Humpback whales make extensive migrations from feeding areas in colder, productive waters in summer months to warm water breeding areas in winter. Recent research has indicated that humpback whales off northern Washington are a somewhat distinct feeding aggregation with fairly little interchange with feeding areas to the north and south. Humpback whales that feed off Washington migrate to winter breeding areas off Mexico and Hawaii.

Status and Trends

Humpback whales have been recovering in a number of areas, although populations in most regions remain well below those that existed prior to whaling. Although most humpback whales occur in waters off the Washington coast, sightings in Puget Sound have become increasingly more common in recent years. This has included several animals that spent periods of two to three months in areas of Puget Sound and the Strait of Juan de Fuca.

Since 2004, an international collaboration of researchers has been conducting an intensive study of humpback whales throughout the entire North Pacific. The study, called SPLASH, will be the first complete census of humpback whales in the entire North Pacific and will determine abundance, trends, population structure, movements, and human impacts.

Impacts to the Ecosystem

Humpback whales feed on both krill and small fish. Most of the whales feeding on krill tend to do so in waters near the continental shelf edge in offshore waters. Humpback whales in inside and more coastal waters typically feed on fish, and this was likely the case for humpback whales in Puget Sound and Strait of Juan de Fuca. The declines in a number of species of small fish, such as herring in Puget Sound, could limit the recovery of humpback whales in these waters.

i. Gray Whales

Gray whales (*Eschrichtius robustus*) make one of the longest migrations of any mammal. The eastern Pacific gray whale travels from winter breeding areas off Baja California to summer feeding areas primarily in the northern Bering Sea and into Arctic waters. While it was once thought all gray whales make this migration, recent research has revealed the existence of a component of the population that can spend the entire spring, summer, and fall feeding in the waters of the Pacific

Northwest, from California to Southeast Alaska. This group has been referred to as seasonal residents, or the Pacific coast feeding aggregation of gray whales.

Gray whales are still hunted in Russia under a provision for aboriginal hunting allowed by the International Whaling Commission. In 1995, the Makah Tribe of Washington asserted their treaty right to whale and resume their historical hunts for gray whales. Their proposed hunt of up to five gray whales a year was the source of legal battles that continue today. To date, only a single whale has been killed (in 1999) by the Makah Tribe. Gray whales also are killed by entanglement in nets and crab lines as well as ship strikes. While there had been concern in the 1980s and 1990s about the role of contaminants in the mortality of gray whales in Puget Sound, tests of gray whale tissues have revealed contaminant levels that are much lower than in many other marine mammals species and that the mortality is the result of other factors.

The eastern Pacific gray whale population had been considered one of the success stories for recovery from commercial whaling. The population had been reduced to a few thousand animals during several different periods of whaling that targeted this species in the 19th and 20th centuries. The population increased steadily to approximately 23,000 to 26,000 whales by the late 1990s. The recovery of the eastern Pacific gray whale led to its removal from the federal list of endangered species in 1995.

Status and Trends

In 1999 and 2000, an unusually large number of dead gray whales were found from Mexico to Alaska. In Washington state, 27 dead gray whales washed ashore in 1999—considerably more than the average of about four a year prior to that. Another 23 whales washed ashore in 2000 (Figure 2-44). Additionally, low numbers of calves were born, and many live animals appeared emaciated. Examination of dead animals revealed most were in very poor nutritional condition and appeared to have starved to death. The overall gray whale population was reduced to about 17,000. This mortality is thought to have been a result of combination of events: a recovery in gray whale numbers to pre-whaling population size and a decline in prey species populations.

Recent research in Puget Sound has revealed three primary patterns in gray whale activities. The main part of the population migrates past Washington in winter and spring en route between winter breeding areas and summer feeding areas. A small number of whales wander into unusual areas of Puget Sound in spring and appear to be stragglers from this migration; they often appear emaciated and often die. A group of about 250 seasonal residents spend springs, summers, and falls feeding in the Pacific Northwest, farther south of the majority of the population. In northern Puget Sound, a small group of regular animals spend two to three months feeding primarily on ghost shrimp in the waters around Whidbey and Camano islands.

Impacts to the Ecosystem

Gray whales generally utilize a fairly unique feeding method. They primarily feed on organisms along the bottom and in the upper layer of sediment that they suck into their mouths and, then, filter through baleen plates. Recent research has revealed gray whales can also be surprisingly versatile feeders, occasionally capturing a wide variety of prey, including fish, krill, and the larvae of fish and crabs.

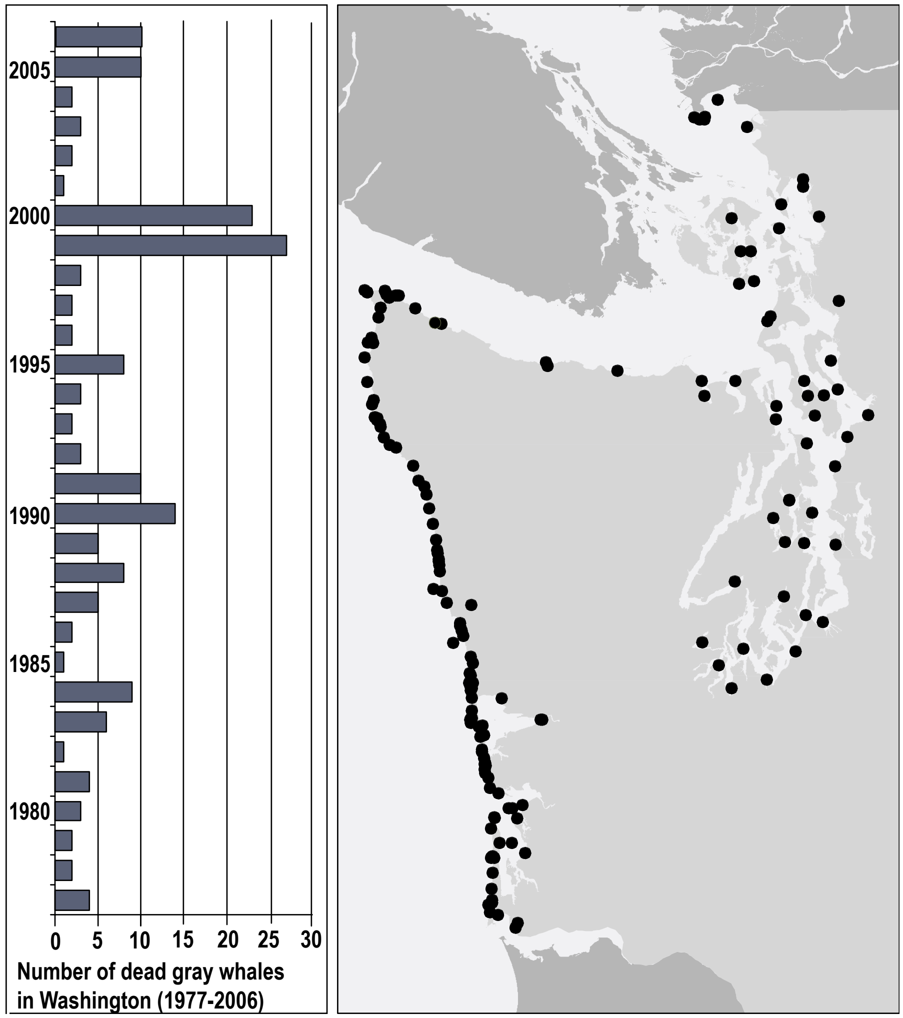


Figure 2-44. Number of gray whale carcasses found in Washington state, 1977 to 2005. There was high mortality in 1999 and 2000. Map shows location of caracasses found since 1977. (Source: WDFW)

10. Aquatic Nuisance Species

Aquatic nuisance species (ANS) are non-native aquatic plants or animals which can out compete native species for habitat and food, altering the natural ecosystem. They also threaten the biodiversity of Puget Sound.

Purple loosestrife (*Lythrum salicaria*), *hydrilla* spp. and *Spartina* spp. are a few examples of plants that currently threaten estuaries, wetlands, rivers, and lakes in the Puget Sound Basin. Non-native tunicates commonly called sea squirts, are animals that multiply rapidly and are a recent arrival to several locations in Puget Sound. The European green crab, Chinese mitten crab, and zebra mussel are ANS that could arrive at anytime and threaten the Sound.

One means of ANS introduction to Puget Sound and its tributaries is ballast water discharged by ships. A large percentage of 52 documented non-native species found in Puget Sound was probably introduced in ballast water discharges. ANS also arrive on fouled hulls of ships, as hitchhikers on imported aquaculture species, in shipments of live seafood and bait and their packaging, and on recreational boats transported into and around the state.

a. Tunicates

Tunicates are primitive invertebrates in the phylum Chordata. They occur in colonies and also as solitary individuals and are aggressive spawners, reproducing as frequently as once every 24 hours. They colonize on many types of marine structures and habitats, overgrowing and smothering other organisms on the seabed, sometimes covering the siphons of infaunal bivalves. Tunicate species have the potential to spread rapidly throughout Puget Sound by traveling on the hulls of recreational and commercial boats.

Status and Trends

In late 2004 and early 2005, researchers found three non-native invasive tunicates in Puget Sound. An Asian colonial tunicate, *Didemnum,* was found in waters off Edmonds, and promptly eradicated at that site. Subsequently, researchers found the species at the Des Moines marina and on mussel lines in Totten Inlet and Dabob Bay. There are also huge infestations off Vancouver Island and in Okeover Inlet on Desolation Sound in British Columbia.

In the summer of 2006, WDFW surveyed for and found the solitary club tunicate *Styela clava* in high densities at Pleasant Harbor marina in Hood Canal and at the Blaine and Semiahmoo marinas. Divers from WDFW attempted to prevent the club tunicate from spreading to other areas by removing all animals that fouled boat hulls at the infested marinas.

Another solitary non-native tunicate, *Ciona savignyi* was found in high densities on geoduck tracts at the south end of Hood Canal near the mouth of the Tahuya River. There were no *C. savignyi* at this site in the 1990s but these invertebrates are now abundant and are the dominant species in this area of Hood Canal. Researchers also reported large populations at the Des Moines marina, Eagle Harbor, Edmonds, and the Tacoma Yacht Club.

b. European Green Crab

The non-native European green crab is not currently found in Puget Sound, but because it is present on Washington's ocean coast, monitoring is underway to patrol for its presence in Puget Sound. Volunteers continue to monitor over 100 sites in the Puget Sound region for the presence of green crab.

c. Atlantic Salmon

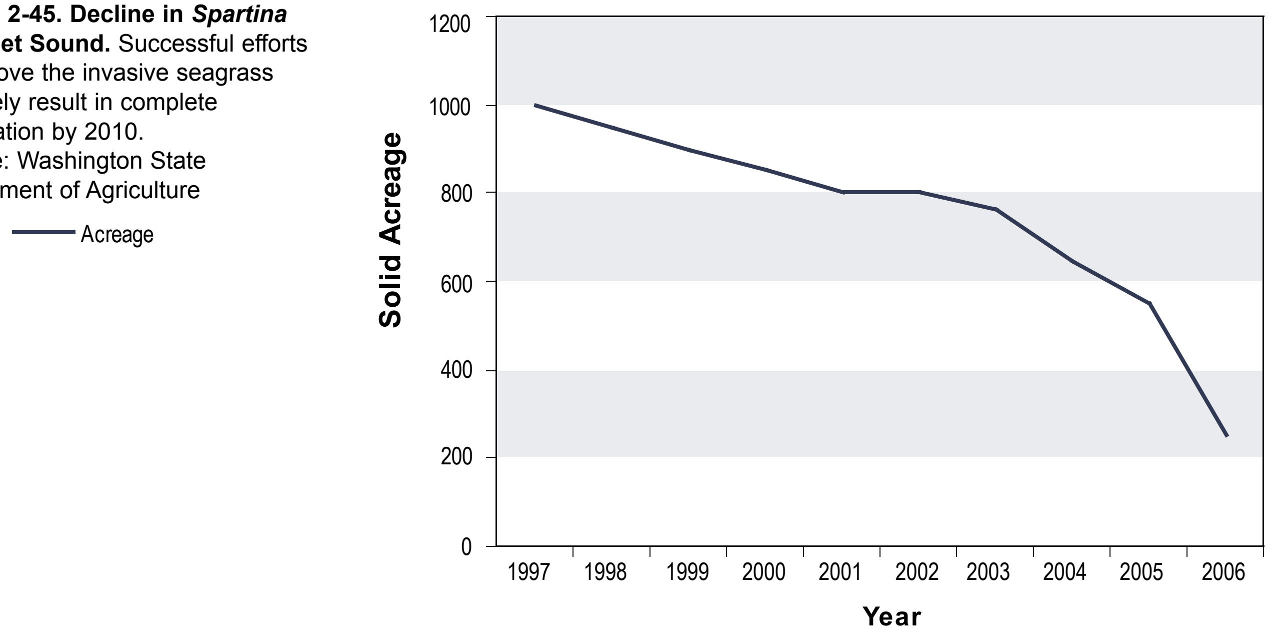
Four locations in Puget Sound have net pens for raising Atlantic salmon (*Salmo salar*). These locations include the Port Angeles Harbor in Clallam County, Rich Passage in Kitsap County, and Cypress and Hope Islands in Skagit County. In addition, private operators raise Atlantic salmon at two hatcheries in Washington—one on Scatter Creek and another at Cinnabar Creek on Mayfield Lake. Scatter Creek, in Thurston County, is a tributary to the Chehalis River, and Cinnabar Creek is in Lewis County; both are outside of Puget Sound.

Between 1996 and 1999, 613,000 Atlantic salmon escaped from net pens in Washington. Less than four percent of these fish were recovered, raising concern that the remaining escapees may reproduce in Washington waterways.

d. Aquatic and Riparian Plants

WSDA lists 29 species of wetland and aquatic plants as being prohibited for sale in the state. Most are not found in this region and some have limited populations.

Figure 2-45. Decline in *Spartina* in Puget Sound. Successful efforts to remove the invasive seagrass will likely result in complete eradication by 2010. Source: Washington State Department of Agriculture



Others, such as invasive *Spartina*, knotweed, and purple loosestrife are found in the Puget Sound region and resource managers are actively controlling their populations.

i. Spartina

Spartina, commonly known as cordgrass, is an aggressive noxious weed that severely disrupts the ecosystems of native saltwater estuaries in the state. It outcompetes native vegetation and converts mudflats into monotypic *Spartina* meadows, destroying important migratory shorebird and waterfowl habitat, increasing the threat of flooding, and severely impacting the state's shellfish industry. *Spartina* spreads by seed production and below-ground root growth.

Spartina was introduced in Puget Sound by various landowners, who planted it to stabilize shorelines. It was also planted at a farm located in Port Susan in the early 1960s as bank stabilizer and for cattle feed.

Four species of non-native *Spartina* are found in Puget Sound estuaries. *Spartina alterniflora* is found in Skagit, Clallam, and in Jefferson Counties. *Spartina patens* occurs at only one location in Jefferson County. *Spartina anglica* is present in Skagit, Snohomish, Island, San Juan, Whatcom, King, Kitsap, and Jefferson counties. *Spartina densiflora,* from South America, is found within Race Lagoon in Island County.

Status and Trends

WSDA partners with local noxious weed control boards, tribal governments and WDFW to eradicate *Spartina*. WSDA has estimated that 520 acres of *Spartina* were treated in Puget Sound and Hood Canal in 2005—approximately 95 percent of the overall infestation. The Puget Sound infestation, estimated at 1,000 acres in 1997, has been reduced by about 46 percent (Figure 2-45). From the spring of 2004 to the spring of 2005, an estimated 16 percent reduction occurred. At the current removal rate, agencies are on track to effectively eradicate spartina from Puget Sound by 2010.

ii. Knotweed

Five species of non-native knotweed plants grow in the Puget Sound basin: Japanese knotweed, giant knotweed, bohemian knotweed, and Himalayan

County	River	Miles surveyed	Acres treated
Whatcom	N and S fork of Nooksack	15	7.5
Skagit	Skagit and Sauk rivers	500	4.5
Snohomish	Stillaguamish River	43	139
Island	County wide		3
Clallam	Dungeness, Hoko, Hoh and Queets rivers	55	94
King	Green/Duwamish	18	9
TOTAL in 2005		**631 miles**	**257 acres**

Table 2-7. River miles surveyed and area of knotweed species treated in Puget Sound in 2005. (Source: WSDA)

knotweed. Knotweed species will grow in most habitats but are most commonly found along stream corridors. It outcompetes native vegetation, including alder and cottonwood trees, forms dense, impenetrable walls along waterways, and potentially reduces precious salmon habitat.

Status and Trends

In 2005, approximately 631 river miles were surveyed for knotweed and approximately 257 acres were treated in the Puget Sound area by tribal governments, local, state, federal agencies, and non-governmental organizations (Table 2-7).

e. Bivalves

The eastern softshell clam is believed to have arrived from the Atlantic in the late 1800s. The varnish clam is a more recent arrival from Asia. First encountered in the San Juan Islands in the 1980s, varnish clams have been increasing in biomass, abundance and distribution. They are now found in the Strait of Juan de Fuca, the San Juan Islands, and as far south as Potlatch in southern Hood Canal. A 2005 WDFW survey on Spencer Spit on Lopez Island found varnish clam densities of up to 80 clams per square foot.

f. Nutria

Nutria (*Myocastor coypus*) are large rodents originally from South America. Nutria consume approximately 25 percent of their body weight in plant matter per day. High reproduction rates coupled with their feeding habits can result in losses to native vegetation and important habitat for wildlife. As semi-aquatic creatures, they prefer aquatic and emergent plants; however, nutria are opportunistic feeders and will consume tree bark, crops, and lawn grasses. They destroy vast swaths of marshes and wetlands and threaten infrastructure such as dike and levee systems.

Status and Trends

Researchers and resource managers have not determined the size of nutria populations in the Puget Sound Basin, nor have they developed a comprehensive management plan for these non-native animals. However, nutria populations in the Puget Sound Basin appear to be on the rise and are currently found in Whatcom, Skagit, Snohomish, King, Pierce, and Thurston counties.

11. Marine Conservation Tools

a. Marine Reserves Monitoring

WDFW has developed a network of 18 marine reserves in Puget Sound (Figure 2-46). These consist of Conservation Areas, which are fully-protected, and Marine Preserves which are partially-protected. A core series of the marine reserves will be monitored on a frequent basis, and additional subtidal reserves will be monitored on a periodic basis. The monitoring plan builds upon field research at many of these sites that was begun as early as 1986. The fieldwork primarily consists of visual censuses conducted by scuba divers along strip transects. Along with estimating fish densities, divers measure individual fish and identify and quantify lingcod nesting activity.

Specific monitoring activities in 2004 included surveying many of the Puget Sound reserves and comparable fished sites. Several reserves in central Puget Sound were visited six times during 2004 as an extension of a study initiated in 1999 to take advantage of the previous information collected at Orchard Rocks. This site was declared as a fully protected reserve in 1998 but was a fished site monitored in 1986 and 1987 and from 1995 to 1997. With the addition of a new fished site treatment at Point Glover, the newly created refuge in a formerly monitored fished area is an excellent opportunity to evaluate the before-and-after impacts of refuge creation with a comparable fished site treatment. WDFW also created several new reserves in 2002. These included subtidal reserves at Admiralty Head and Keystone Jetty in Admiralty Inlet and Zee's Reef in southern Puget Sound. Monitoring was initiated at Zee's Reef in 2002 with six surveys conducted again in 2004. The reserve at Colvos Passage was also monitored during the same survey series.

The marine reserve monitoring studies conducted in the San Juan Islands, Hood Canal, and central Puget Sound confirmed that most marine reserves had higher densities of copper rockfish and lingcod than comparable and nearby fished areas. These fishes were also larger in the long-term reserve at Edmonds (Brackett's Landing) than at the fished areas. In Hood Canal, where the existing reserves amount to almost 20 percent of the available nearshore rocky habitat, increasing sizes of copper rockfish have been observed since 1996 at a site set aside as a reserve in 1994. The densities of copper rockfish are significantly greater in the Hood Canal reserves than the fished area. In the San Juan Islands, rockfish and lingcod densities in the reserves are also greater than at nearby fished areas, but there have not been any discernible trends in size or density for copper rockfish over a span of 10 years of monitoring and 12 years after reserve creation. For lingcod at these sites, the winter-time densities are substantially greater than in fished areas, but densities in both reserve and fished area treatments have been increasing. At Orchard Rocks, the central Sound reserve created in 1998, there has not been an increase in copper rockfish abundance, but lingcod abundance has increased.

The analysis also found a major change at the long-term reserve at Edmonds. The study site once harbored a sizeable school of large copper rockfish that conferred a high estimated reproductive advantage on the long-term reserve compared to fished areas. Since 1999, this school has disappeared with a resulting decrease in the density of copper rockfish at the site. During the same period, lingcod abundance has dramatically increased simultaneously with the decline in copper rockfish. While a number of competing hypotheses to explain these patterns cannot be ruled out, the shift to a site dominated by large piscivores may reflect a shift in the trophic dynamics of the reserve.

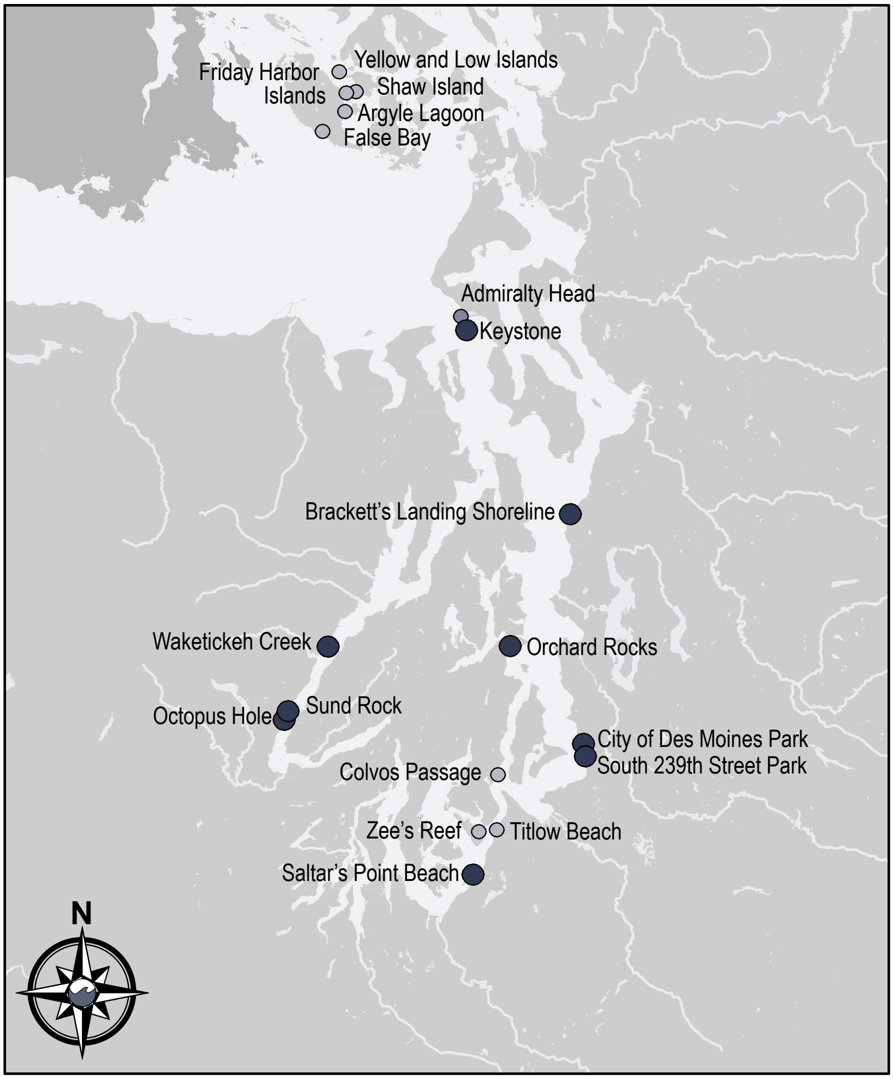


Figure 2-46. WDFW non-tribal marine reserves in Puget Sound. Conservation Areas are fully-protected, and Marine Preserves are partially protected. (Source: WDFW)

- Fully Protected Conservation Areas
- Partially Protected Marine Preserves

12. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided based on the results of the studies reported in the document. The recommendations related to biological resources and progress made through 2006 on those recommendations are summarized below:

Recommendation from the *2002 Update Report* for Biological Resources	Progress made through 2006 on recommendations in the *2002 Update Report*
Monitoring designed to understand dynamics of stocks for populations should include organisms at a range of tropic levels in addition to the species of interest. Results have shown the importance of considering food web interactions in understanding a population in addition to direct relationships with the physical environment.	• Food web dynamics are beginning to be understood through the passage of toxic contaminants through trophic layers (via herring, salmon, and marine mammals). • Trophic studies are also being initiated in Hood Canal and Puget Sound. • Synoptic surveys for fishes also collect information on macroinvertebrates.
Scientists and resource managers need to increase their focus on efforts to understand the causes underlying declining population where management actions have not brought expected improvements, such as with specific groundfish species.	• WDNR initiated the Eelgrass-Stressor Response Project to investigate factors responsible for eelgrass decline. • Studies on Marine Protected Areas and comparable fished areas have shown that fishing is the major factor affecting rockfish and lingcod size and density. These and other studies indicate lingcod recovery may affect the abundance and recovery of rockfish. • Studies in Hood Canal have shown that hypoxia can kill substantial portions of fish populations and limit and affect the distribution of benthic infauna.
Scientists need to explore new techniques that may increase the scope of monitoring studies with limited funding resources. Examples include the use of remote sensing platforms (aircraft, satellite) to replace or augment ground surveys and automated instrumentation to replace manual data collection wherever possible.	• Sea floor mapping tools have been utilized to map the bathymetry of portions of the San Juan Archipelago. • Remote-operated vehicles are providing a platform to study marine resources in both shallow and deep waters.
Wherever appropriate and feasible, multi-disciplinary monitoring should be employed (such as coupling population surveys with collection of toxic contaminant or physical environmental data).	• Combined monitoring of sediment and water quality parameters as part of the PSAMP program have provided insight into the effects of low DO on infaunal communities in Hood Canal.
Scientists need to focus on the detection of ecosystem-level changes, (e.g., changes in the structure of food webs that may not be obvious from a species or population perspective but may be fundamentally more significant.)	• Analysis of infaunal invertebrate communities in Hood Canal are providing insight into ecosystem-level effects of low DO. • Changes in communities and declines in seagrasses in the Strait of Georgia that my be linked to climate-driven changes in precipitation (see Habitat chapter) have been revealed by PSAMP monitoring. • Studies in marine reserves and from surveys provide key information on the changing structure of the food web.
Since its release in 2000, the ShoreZone Inventory has been widely used by scientists and planners. More than 1,000 copies of the digital data have been distributed in response to data requests. Datasets like the ShoreZone Inventory can be used to improve resource management and land use planning. However, additional funding is needed for data distribution and support. Too often, funds are not provided because the importance of these tasks is not recognized. There is also a need for dedicated mechanisms to fund updating datasets and integrating feedback from users.	• While the publishing of studies, reports, and databases in bound media are still important, researchers in Puget Sound have made great progress in placing databases, inventories, and reports on the web. This has resulted in thousands of web hits and downloads of scientific information and has substantially alleviated the need to print and distribute reports and data disks. As an example, the ShoreZone Inventory has been queried by thousands and data CDs are no longer requested.

Recommendation from the *2002 Update Report* for Biological Resources	Progress made through 2006 on recommendations in the *2002 Update Report*
Results represented in this chapter underscore the need for consistent long-term data on biologically relevant environmental variables that scientists can use to interpret changes in key biological populations. This type of data and subsequent analysis will be needed to help increase understanding of the influences of human-caused environmental stressors and corrective actions.	• *The 2007 Puget Sound Update* report summarizes the latest results in long-term biological monitoring that are critical for improving our understanding of Puget Sound ecosystems. Efforts should be continued to collate and analyze species status reports. • Fishery-independent surveys are providing the means to evaluate groundfish populations. This has become especially important since fishery data has been greatly affected by new management strategies.

Moving forward on Puget Sound Science

In looking ahead to what recommendations to report on in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in the *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound,* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth in by the Puget Sound Partnership, PSAT, and PSAMP that are related to biological resources (Chapter 2 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A):

Goal: Puget Sound Species and the web of life thrive.

- Terrestrial, aquatic and marine species exist at variable levels into the future and biodiversity of the overall ecosystem is naturally maintained.
- Invasive species do not significantly reduce the viability of native species and the functioning of the food web.
- The harvest of fish, wildlife, shellfish and plants is balanced, viable and ecosystem based.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 6. Protect species diversity; manage Puget Sound to protect the full range of its biological diversity.

Strategies:

- Achieve significant progress on overall ecosystem and food web protection and recovery to support recovery of the at-risk species.
- Implement the *Puget Sound Salmon Recovery Plan,* the *Hood Canal Summer Chum Recovery Plan,* the *Recovery Plan for the Coastal-Puget Sound Bull Trout* and the *Proposed Conservation Plan for Southern Resident Killer Whales (Orcinus orca)*. Use monitoring, coordination, and adaptive management to evaluate and modify the implementation.

- In anticipation of completion of a rockfish conservation plan, support regulatory and voluntary tools for rockfish recovery.
- Launch a multi-agency effort to assess the relative abundance and geographic distribution of major forage fish species in Puget Sound as the basis for management and recovery strategies.
- Identify research needs and develop management strategies for marine bird populations considered at risk.
- Increase efforts to reestablish and protect Puget Sound Olympia oyster populations.

Detailed recommendations for further research and monitoring

Many of the following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as recommended actions in the 2007-2009 Puget Sound Conservation and Recovery Plan. Progress towards these and previous recommendations will be reported in the next of the Puget Sound Update.

Marine Species Assessments

- A shared agreement is required that establishes and funds a long-term strategy and system for monitoring the status of species at risk, sustainable populations of species and food web elements.
- A complete forage fish assessment, monitoring and research plan tailored to important species in Puget Sound and compatible with the Fish and Wildlife Commission's Forage Fish Management Plan is designed and implemented. This plan should include:
  - An assessment of forage fish populations and productivity.
  - Identification and mapping of forage fish spawning areas and tracking the number of forage fish spawning grounds in healthy condition.
  - Studies to measure forage fish predation by marine birds, fish, and marine mammals.
- Develop strategies to assess and conserve dogfish, Pacific cod, walleye Pollock, Pacific hake, and other depressed or keystone species in the Puget Sound ecosystem. These strategies should include modeling demographic structure of key groundfish species and develop models that link transfer among lower and higher trophic levels.
- Initiate monitoring of plankton (both zooplankton and phytoplankton) communities in Puget Sound. Develop linkages to phytoplankton and understand the dependencies by juvenile fishes. Protect Puget Sound from invasive phyto and zooplankton species through ballast water management.
- Continue ongoing monitoring of marine bird populations and investigate causes of ongoing declines; initiate long-term monitoring of abalone, sea urchin, cucumber, Dungeness crab and geoduck populations.
- Track biodiversity in intertidal biotic communities throughout Puget Sound.
- Develop studies and information that identify the effects of climate, harvest,

The Role of Science
Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.
- Direct new monitoring activities to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance, and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

pollution, habitat loss, and other stressors on key species and ecosystem elements and that distinguish these from natural variation.

Habitat and Fisheries Management

- Use marine reserves to understand baseline conditions, especially trophic structure and the impacts of fisheries. Continue monitoring marine reserves and determining their potential role as a fisheries management tool and their effectiveness in recovering declining species such as rockfishes.
- Rationalize fisheries of invertebrates, salmon, and groundfish with the need for ecosystem function. This would include tracking the number of fisheries, not limiting the productivity of marine species. Compare fishery-dependent and independent stock assessment methods to each other for status and trends of indicators.
- Assure invasive species do not limit the persistence of naturally occurring species by developing a systematic screening process, limit the sources of invasion, and controlling their spread through early eradication and knowledge of limiting life history requirements.

Modeling

- Link processes, structure, habitats, and stressors to species through a conceptual model. Use this model to organize and communicate scientific information. Develop cause and effect models that predict the impacts of harvesting, invasive species, bulkheading, climate change, and other disturbance.
- Assess the key predator-prey linkages between major guilds and habitat complexes and the effectiveness of modeling with ECOPATH and ECOSIM.

Processes and Connections

- Assess the relationship between biodiversity, ecosystem health and productivity. This would include assessing whether density dependent effects are suppressing the recovery of species at risk (Allee Effect).
- Continue on SMVP for eelgrass; develop additional focus studies where eelgrass has declined in herring spawning areas. Test for causal linkages between success of spawning and decline of eelgrass. Develop methods to survey the status of subtidal kelps and other algae and develop understandings of how climate change, eutrophication, and habitat change can affect their abundance.